JAAKKO PÖYRY

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Complementary Scientific Review of the Proposed Alberta-Pacific Pulp Mill Project Environmental Impact Assessment

Executive Summary

prepared for Alberta Research Council
ARC Contribution Series 1857

JAAKKO PÖYRY

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COMPLEMENTARY SCIENTIFIC REVIEW OF THE ALBERTA-PACIFIC PULP MILL PROJECT

EXECUTIVE SUMMARY

This executive summary is respectfully submitted to the Alberta Research Council.

Juhani Anhava
Jaakko Pöyry Oy
Helsinki, Finland

DATED at the city of Helsinki, Finland, this 9th day of July, 1990.

1
PROJECT BACKGROUND AND DESCRIPTION

The Complementary Scientific Review of the Proposed Alberta–Pacific Pulp Mill Project (ALPAC) has been carried out to study the earlier environmental impact assessment (EIA) and to find complementary scientific data to better assess the potential and probable effects of the proposed development. Unlike the previous Review Board the team has also reviewed the effluent releases and water pollution control measures in the context of the entire Athabasca and Peace River watersheds.

The terms of reference for this project were to review all of the available data on the effects of chlorinated organic compounds and the biological oxygen demand that would be discharged in the pulp mill effluents. Air pollution, solid waste and other environmental issues, less crucial than the problems posed by water pollution, would be discussed only in relation to specific questions that were not completely addressed in the previous review in 1989.

The team established for the complementary review had the opportunity to discuss the project with three members of the original Review Board: Mr. Ron Epp, Prof. Bill Ross and Prof. David Schindler, each of whom gave an excellent briefing on the work of the board. They also provided the team valuable advice on open questions and local conditions, which were very important for focusing the authors' efforts to the essential issues in the somewhat limited time available.

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POLLUTION CONTROL REGULATIONS AND MEASURES

The proposed ALPAC mill was compared to the other pulp mills in operation and under construction in Alberta and in other parts of Canada and with some major pulp producing areas throughout the world. At the time this study was conducted the regulations in Alberta were more strict than in British Columbia, Ontario and Quebec, and are more stringent than the proposed new Federal Regulations in Canada. A comparison with Scandinavian kraft pulp mills, based on the most recent official monitoring reports available clearly showed that operating mills at Hinton (Weldwood) and Grande Prairie (Procter & Gamble) are well below or at the average Scandinavian level already. The new bleached kraft pulp mill at Peace River (Daishowa) starting up in July 1990 will correspond to the most modern mills in Finland and Sweden, and the ALPAC bleached kraft pulp mill would have lower discharges of chlorinated organic compounds (AOX) and biological oxygen demand (BOD_5) than any other bleached kraft pulp mill operating at the time of this report. If the effluent AOX release regulations for pulp mills in Alberta are compared with the strictest requirements for

AOX currently in force (in Australia and the Federal Republic of Germany – requiring less than 1.0 kg AOX/air dried tonne of pulp (ADt)) the licensed AOX loadings of Weldwood–Hinton and proposed license limit for the ALPAC at 1.5 kg/Adt are slightly higher on the monthly average basis. At present time, however, there are no bleached kraft pulp mills either in operation or in construction, in Australia or the Federal Republic of Germany, which would meet the 1.0 kg AOX/ADt guidelines issued in 1989. The proposed ALPAC mill has the potential to reach the 1.0 kg/ADt limit and could be one of the first mills in the world to do so.

The review has attempted to provide a detailed environmental evaluation of all pulp mills in the study area so that an assessment can be made of the potential cumulative effects of all the pulp mills operating along the Athabasca River. Because of the shortage of monitoring data (1) for AOX, (2) on the fisheries in the middle reaches of the Athabasca River, and (3) on possible fish tainting from effluent sources other than pulp and paper mills, the evaluation has been made on the basis of information on the technology being used or planned for the mills and on the public domain technical and scientific literature. In order to be comprehensive, some data and conclusions from the earlier EIA report have been repeated in this report. However, more attention has been paid to new issues where relevant complementary data has been discovered.

The report includes a comprehensive technical evaluation of the proposed ALPAC bleached kraft pulp mill. Special attention has been paid to the water pollution issues, focusing on potential methods of restricting the formation and discharge of AOX. The study is based on the same technical proposal that was presented in public hearings and in the report of the original EIA Review Board. However, it is recognized that in the end of April ALPAC issued a more ambitious technical proposal, which at this time remains confidential. The revised ALPAC proposal is known to describe technologies for improving the bleaching process which is claimed to further reduce the formation and release of chlorinated organic compounds. Such an improvement would have some additional impact on reducing the toxicity effects of AOX on the environment rather than reducing any other single loading parameter like BOD_5, COD or phosporous. As the new ALPAC proposal remains confidential, a short description of other possibilities to reduce the formation of AOX compounds has been included by the authors of this report. According to recent Canadian research (Wrist 1990), the benefits of AOX reduction to levels below 1 kg AOX/ADt are rather limited; however it would decrease the probability of discovering some new hazardous chlorine compounds at a later date.

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FUTURE ENVIRONMENTAL IMPACTS

In this context the ALPAC mill could not be reviewed alone and data on other operating mills and mills under construction were included. The past emission levels from the bleached kraft pulp mill at Hinton were estimated for different periods of operation and their effects were assessed to the extent relevant and practical. The Hinton pulp mill has been in operation on the upper reach of the Athabasca River since 1957 and with modern technology its capacity has been doubled in the past two years. Due to the natural sedimentation conditions described in detail in the report, the probability of finding dioxins and furans in the main stream of Athabasca River is almost negligible. It seems more likely that the dioxin and furan compounds have, little by little, been moving downstream with suspended particulate material and become diluted so close to background levels that they cannot be detected in the sediments or fish in the delta region of the Athabasca River. If they can be detected with high resolution analytical methods it is unlikely that there is any significant difference between dioxin and furan concentrations in the delta and in natural reference areas.

The aquatic chemistry, particularly the dissolved oxygen (DO) content of the Athabasca River upstream from the Grand Rapids, was reviewed. Assuming that the mills will meet the requirements included in their operating licenses, the situation with BOD_5, chemical oxygen demand (COD), AOX and DO will not essentially change from 1990 to 1993. This is due to more efficient water pollution control and the improved technology at the Weldwood mill in Hinton. If the ALPAC mill is built, the loadings of the above-mentioned impurities will increase slightly when ALPAC is running at full capacity. The effects on DO concentrations in the Athabasca River would be restricted to a about 200 km long area in the middle of the river (Athabasca City–Grand Rapids). The lowest DO content of the river water without ALPAC would be about 6 mg O_2/l. With the proposed ALPAC mill it would be between 5–6 mg/l, which would not be limiting the survival of adult fish in this area. Since the major spawning areas for fall-spawners are believed to be either far up- or downstream, the most sensitive eggs and larvae would not be exposed to the decreased DO levels. The DO content would be 6–9 mg/l elsewhere in the Athabasca River, and it would not be influenced by the proposed ALPAC pulp mill. It is obvious that the oxygen conditions would not be a problem during snow melting and open water seasons and spring-spawning fish would not be affected by low DO conditions.

The phosphorous and nitrogen discharges from the pulp mills were estimated and the total phosphorus loading was compared to the overall phosphorus loading of Lake Athabasca. The phosphorus loading from the pulp mills does not have a major contribution to the annual phosphorus loading. However, it is expected that a considerable part of the P-loading is not biologically available for algae. This fact should of course be confirmed and, if incorrect, some additional requirements to limit the quantity of phosphorous in the effluent should be set on the pulp mills along the Athabasca River. As neither phosphorus nor nitrogen seem to stand out as the main limiting factor for the algae production of the lake, some additional research could also be carried out to assess the effects of these nutrients. Any nutrient discharges to Peace River would probably have their first effects, if any, on the eutrophication in the Great Slave Lake.

From the perspective of the Athabasca and Peace River watersheds, it would be worthwhile to consider optimizing the locations of pulp mills being built after the year 2000 by preparing a regional master plan for development for forest industries that would minimize potential negative effects on the environment.

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IMPACTS ON FISH AND FISHERIES

Information on the population of fish, their spatial distribution, migrations and commercial importance in the Athabasca and Peace River watersheds is limited although some data were provided to the original review and are included in this report. In the study area between Athabasca and the Grand Rapids the information seemed to be extremely limited, however, Alberta Environment reviewed the existing baseline data with the study team which allowed the team to make some preliminary statements, as well as a few recommendations for further studies.

In the Athabasca River System commercial fishing is restricted to the river delta, and in particular, to the Lake Athabasca. Recreational fishing is currently being practised mainly in the Athabasca River from Hinton upstream and in the tributaries. Little is known about current recreational fishing habits in the reach between Whitecourt and Grand Rapids. More information is also needed with respect to not only the extent of recreational fishing in that area, but also about fish tainting, in at least the immediate vicinity of the present pulp mills, as well as in the reach between Fort McMurray and Lake Athabasca. Other sources of contamination should also be taken into account. A dioxin and furan survey in fish from the neighbourhood of the kraft pulp mills is a logical start, and actually some 80 fish caught a few kilometres downstream of Hinton and Grande Prairie are now being analyzed by Department of Fisheries and Oceans in Ottawa. This work should be extended in the near future also to areas further from the mills and to reference areas which have not seen any pulp mill effluent.

According to results from fish physiological studies performed throughout the world, chlorinated phenols, guaiacols and catechols are excreted from fish within areas under continuous or intermittent exposure and the above-mentioned compounds do not bioaccumulate to the same extent as some other well-known chlorinated compounds (DDT, PCB, etc.). The half-lives of chlorinated dioxins and furans in fish are much longer and these bioaccumulate strongly. Migration of fish and variations in the concentrations of the above mentioned chemical impurities play a vital role in the bioaccumulation and transport of dioxins and furans across territorial waters. It is recommended that future analysis be made from relatively old fish in order to have as conservative an estimate as possible for assessments of human risks. Such analyses also can reflect any bioconcentration caused by the emissions during the past 30 years. These samples should at least be taken from the spawning areas below the Grand Rapids as well as from older fish from the reach between Hinton and the Grand Rapids.

5
SPATIAL EXTENT OF ENVIRONMENTAL IMPACTS

The complementary review starts with a short introduction to the study area to make it possible to have an overview of the problems as a whole. It proved necessary to make a clearer distinction between the Athabasca and Peace River watershed areas than anticipated. This was due to the fact that, first of all, effects on the DO were clearly limited to upstream Grand Rapids in Athabasca River. Any problems with DO were extremely local in Peace River. No effect whatsoever on DO was expected in the Slave River that could be attributed to pulp mills upstream.

Questions concerning the effects of AOX are far more complicated than those of DO. It is not possible to give a definite statement on the traces of dioxins and furans found in the fish tissues from the Slave River. The levels detected were very close to the background levels measured in non-polluted Scandinavian lakes and rivers and no non-polluted background data were available for Alberta and the Northwest Territories. Without more detailed data on other dioxin and furan isomers than the analyzed 2,3,7,8-dibenzodioxin and 2,3,7,8-dibenzofuran it is impossible to judge whether or not these compounds are of pulp mill origin.

Until more detailed analyses for the dioxins and furans are available, the assumption that the effects of the pulp mills in Athabasca and Peace River watersheds do not extend downstream to the Slave River cannot be excluded. As far as Athabasca River is concerned it is important to note that Lake Athabasca is very likely an important sink for most impurities coming in with the river water. These impurities include suspended solids and phosphorus, dioxins and furans. Dioxins and furans which have extremely low solubility in water are likely to be adsorbed on the surfaces of tiny particles which sediment out in the delta of Athabasca River.

6
ECOTOXICOLOGICAL AND HUMAN HEALTH EFFECTS

There are no anticipated ecotoxicological risks to the human population caused by the discharge of chlorinated substances from pulp mills into nearby waterbodies in the study area. In addition, published information from the literature review showed that inhabitants of the Lake Athabasca area and the Wood Buffalo Park consume less fish than was initially estimated.

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Main Report

prepared for Alberta Research Council
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JAAKKO PÖYRY

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This report is respectfully submitted to the Alberta Research Council.

Juhani Anhava
(Team Leader)
Jaakko Pöyry Oy
Helsinki, Finland

Hannu Jäppinen
Jaakko Pöyry Oy
Helsinki, Finland

Johan Mjöberg
Johan Mjöberg
Jaakko Pöyry AB
Stockholm, Sweden

Jorma Ahokas
Royal Melbourne Institute
of Technology
Melbourne, Australia

Maarit Priha
Maarit Priha
Finnish Pulp and Paper
Research Institute
Espoo, Finland

Douglas Holdway
Royal Melbourne Institute
of Technology
Melbourne, Australia

Jukka Tana
Finnish Environmental
Research Group
Vantaa, Finland

DATED at the city of Helsinki, Finland, this 15th day of June, 1990.

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The authors wish to thank the many individuals and organizations that contributed to the various components of this review.

During the original fact-finding trip to Alberta, the Alberta Research Council provided office space, secretarial and administrative support, arranged meetings with the appropriate individuals and organizations and a lease of the database from the original 1989 Environmental Impact Assessment Review. Dr. Gordon Bird of the Alberta Research Council, who acted as Project Supervisor for this project, coordinated all of these activities and handled the arrangements for meeting with individuals and organizations outside of the Research Council.

Special thanks are due to Professors Bill Ross and David Schindler of the original EIA Review Board who contributed their time to brief us on technical aspects of the EIA Review and directed us to much pertinent information in the EIA database and elsewhere. Mr. Ron Epp, also a member of the original EIA Review Board, flew two members of the review team along the Athabasca River valley and provided much useful insight into the local physical environment. His comments on the original EIA Review were also useful in putting many of the issues into context.

Alberta Environment provided access to their technical experts for discussion and arranged access to a vast amount of technical data that had been presented to the EIA Board. Discussions with Leigh Noton and Bryan Kemper were particularly useful.

Alberta Pacific and the other pulp mill operators along the Athabasca and Peace Rivers cooperated with us in providing access to information about their mills and process technology and effluent treatment procedures.

The contributions of all of the above individuals and many other contributors organizations are gratefully acknowledged.

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1
BACKGROUND AND OBJECTIVES

Alberta-Pacific Forest Industries Inc. (ALPAC) proposes to build and operate a bleached kraft pulp mill in the County of Athabasca # 12 in the vicinity of the town of Athabasca (ALPAC, 1989a and ALPAC 1989b).

In order to review the environmental impacts of the proposed mill, a review board was established jointly by the Alberta and the federal governments. After a thorough review (including public hearings and study of a large number of submissions) the review board recommended that the ALPAC project not be approved until more detailed studies were available which indicated that the proposed mill would not be detrimental to the river's ecosystem nor would it create any hazards for downstream users.

The major reason this recommendation was the discharge of chlorinated organic compounds (AOX) with the mill bleach plant effluents into the Athabasca river. The review board also expressed concern about the dissolved oxygen (DO) situation caused by the effluents. This affects the river between the proposed mill site and the Grand Rapids.

The Alberta Research Council engaged the expertise of Jaakko Pöyry Oy to perform a complementary review and evaluation of all the data available and related to the ALPAC Environmental Impact Assessment (EIA) Review, with special emphasis on AOX and on DO in the Athabasca River. The study was to focus on pulp mill technology, river dynamics, fate of contaminants, and impact on the aquatic food chain, and the effects of the mill effluents on the Athabasca River and watercourse downstream. The terms of reference for the study are given in Appendix I.

The area to be included in the study consisted of the Athabasca River, both upstream and downstream from the ALPAC pulp mill site, as well as Lake Athabasca and Slave River. The contribution of the Peace River to water quality along the Slave River was to be taken into account.

The abbreviations are explained when they occur first time in the text as well as in Appendix II

2
GENERAL DESCRIPTION OF THE STUDY AREA

A map of the study area, illustrated in Figure 2/1, shows the location of the Athabasca and Peace Rivers in the Province of Alberta. These two rivers have their sources in the Rocky Mountains, in the Province of British Columbia. The Athabasca River discharges into Lake Athabasca, and this lake discharges into the Slave River, running north to Great Slave Lake in the Northwest Territories. The Peace River runs into the Slave River, north of Lake Athabasca. Eventually these water systems empty into the Arctic Ocean. The physical framework of the Athabasca and Peace River systems is described in detail in Chapter 7.

One significant topographical feature, some 200 km downstream of the proposed ALPAC site, is the Grand Rapids (Figure 2/1) where river aeration takes place.

The map in Figure 2/1 also shows the pulp mills operating along the two rivers. Of these mills only those of Fletcher Challenge, Finlay, Procter & Gamble and Weldwood existed before 1988. In 1988 the mills of Fibreco and Millar-Western were added and in 1990 the mills of Daishowa, Alberta Newsprint and Alberta Energy Co. will become operational.

Weldwood has recently carried out a major modernisation and expansion. The rebuilt mill became operational during spring 1990 and is presently being fine-tuned. Procter & Gamble has expressed an intention of a major expansion of its pulp mill to be finished by 1993. Louisiana Pacific is also planning to construct a mill at Chetwynd by the Peace River in B.C. There have also been recent indication of a plan to expand their CTMP mills.

Other major industries in the study area also contribute to the materials discharged into the water shed, the largest being the tar sand operations at Fort McMurray.

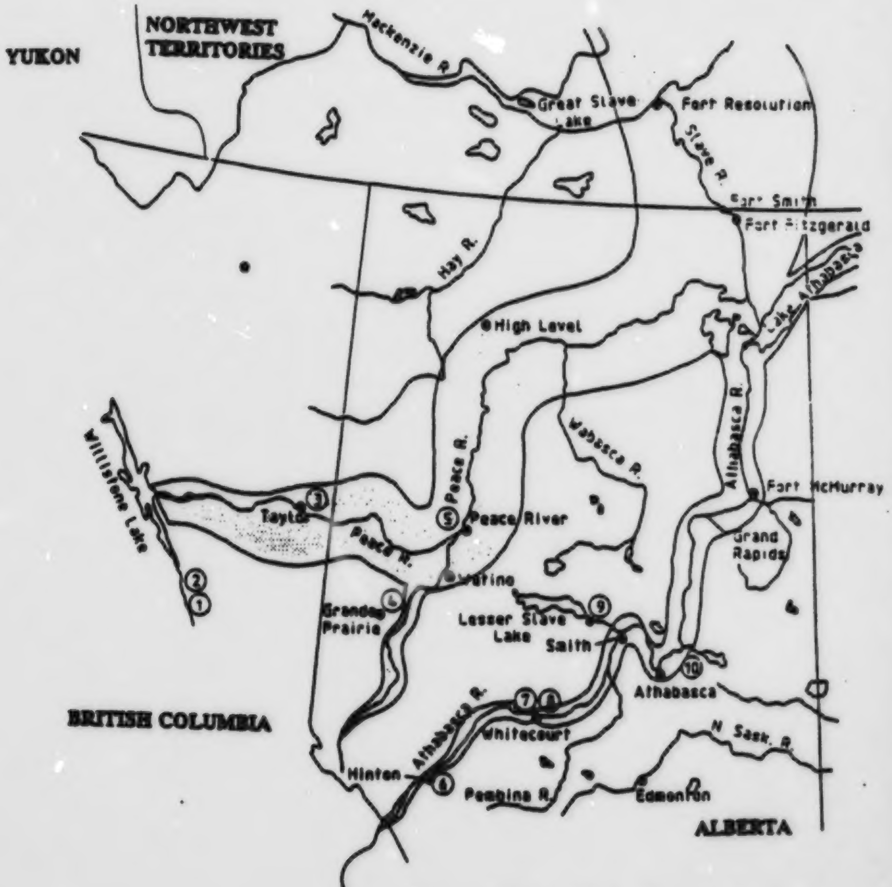
Recently, ALPAC submitted a proposal to build and operate a bleached kraft pulp mill about 50 km northeast of the Town of Athabasca. The mill would produce market pulp primarily from hardwood although some softwood would also be used. The mill's potential capacity would be 1500 air dried tonne of pulp per day (ADt/d) for hardwood pulp and 1250 ADt/d for softwood pulp in one fibre line.

The ALPAC mill, as proposed, would take advantage of recent developments in pulping technology and emission control. This would make the mill one of the least polluting bleached kraft mills in the world. ALPAC has also expressed an interest and willingness to incorporate new technology for improved emission control as it becomes available in the future (EIA 1990).

An important factor to consider in studying any facet of the aquatic life in the Athabasca and Peace Rivers is the extended period of almost half of the year when the river is covered by ice.

FIGURE 2/1
Pulp Mills in the Study Area

1 Fletcher Challenge
2 Finlay Forest Ind.
3 Fibreco
4 Procter & Gamble
5 Daishowa
6 Weldwood
7 Alberta Newsprint
8 Millar-Western
9 Alberta Energy
10 Alberta-Pacific


YUKON
NORTHWEST TERRITORIES
Mackenzie R.
Great Slave Lake
Fort Resolution
Slave R.
Fort Smith
Fort Fitzgerald
Lake Athabasca
Hay R.
High Level
Williston Lake
Peace R.
Wabasca R.
Athabasca R.
Fort McMurray
Taylor
3
5
Peace River
Grand Rapids
2
1
Watino
Grande Prairie
4
9
Lesser Slave Lake
Smith
10
Athabasca
7
8
Whitecourt
N. Sask. R.
BRITISH COLUMBIA
Hinton
6
Pembina R.
Edmonton
ALBERTA
0
100
200
300
400
500
-KM-
Columbia Icefields

3
POLLUTION CONTROL GUIDELINES

3.1
Legislation in Canada

The responsibility for environmental protection in Canada is shared between the federal government and the individual provincial governments. The provincial jurisdiction flows from their overall responsibility for managing the natural resources that fall within their territory. Until 1988 the federal governments's role was based on its responsibility to protect the fishery resource, both offshore and in Canadian rivers and lakes. Federal regulations applied only to those pulp mills which were constructed later than 1970. All other mills were left to provincial regulation, which varied across the country both in setting of the water quality standards and strictness of enforcement of the standards. In 1988 the federal government's role was greatly expanded by the passage of the Canadian Environmental Protection Act (CEPA), which gave it powers to regulate all forms of toxic substances entering the environment. It now appears probable that new federal regulations proposed this spring 1990, will become the base standard across Canada, with individual provincial governments reserving the right to impose locally more restrictive limitations where special water quality requirements are needed to protect sensitive ecosystems. Although much negotiation has still to take place, it now appears probable that the federal effluent regulations will eventually be administered by the provinces, together with any additional provincial regulations (Wrist 1990).

In April 1990 the federal government, after discussions with the provinces, issued its proposed new regulations for the pulp and paper industry under both the Fisheries Act and CEPA. (See Appendix III). These new proposals cover the control of chlorinated dioxin and furan in the effluents of bleached pulp mills, as well as the biological oxygen demand (BOD), total suspended solids (TSS) and acute toxicity of discharges from all mills. Although the federal government and four provinces have declared their intention to establish organic halogens (AOX) standards in the near future, the need, form and severity of the proposed AOX standards are still being studied.

The proposed federal BOD and TSS regulations are also shown in Appendix III. The standards are the same for all grades of pulp, except dissolving pulp. In the case of BOD, upward variances may be granted on a case by case basis, if the mill can demonstrate that it has taken all reasonable measures to reduce its raw waste load, and that its treatment plant is operating at greater than 85 % efficiency. A violation would occur if either the monthly or daily limit of effluent release is exceeded. The acute toxicity test on rainbow trout is considered the most critical of the conventional parameters imposed by the federal government. In addition to the acute toxicity testing of salmonoid fry at regular intervals, monitoring of the treatment plant performance will be required several times a week, using Daphnia Magna (Wrist 1990).

The Federal Government has already declared dioxins and furans to be toxic substances requiring regulation under CEPA. Its proposed regulations for the bleached pulp industry are divided into two parts. First, the use of defoamer additives which contain more than 20 parts per billion (ppb) of dibenzo-p-dioxin (DBD), or 40 ppb of dibenzofuran (DBF) will be prohibited. Second, a ban has been imposed on the sale of, or the use of wood chips from lumber mills that use pentachlorophenol as a sapstain preventative. Suppliers of both chips and defoamers have to certify that their products meet governmental requirements. In addition, the mills have to operate their bleach plant in such a way that there is no measurable 2,3,7,8-tetrachlorodibenzodioxin (2378-TCDD) or 2,3,7,8-tetrachlorodibenzofuran (2378-TCDF) in the effluent. It is anticipated that these levels will be less than 20 parts per quadrillion (ppq) 2378-TCDD and 50 ppq 2378-TCDF. In addition, monitoring and reporting of the other TCDD and TCDF homologues will be required. Thus, it can be seen that the new regulations of the Fisheries Act have been designed to protect the aquatic environment against short-term damage caused by lack of dissolved oxygen (DO), by solids deposition, or by the acute effects of toxic substances. The regulations under CEPA which apply to dioxin and furan are intended to prevent the longer term effects of their toxic bioaccumulation up the food chain (this recently led to the closing of several shellfish harvesting areas on the west coast of British Columbia as well as the fish consumption advisories for a number of inland rivers).

A majority of bleached kraft mills already have installed biological effluent treatment plants. Some already meet the proposed federal standards, but most bleached kraft mills need to be upgraded to meet the new toxicity requirements. Few newsprint mills currently have more than primary treatment plants and will need to install secondary plants. Although initially designed for BOD reduction, it is now recognised that biological treatment plants serve as the primary tool for controlling acute toxicity in the effluents of both mechanical and chemical pulp mills, and that it is necessary to optimise their design for BOD and toxicity reduction. This dual function necessitates the development of designs with longer retention times than might otherwise be needed for BOD reduction alone (Wrist 1990).

3.2
International Guidelines

Waste water from pulp mills will have an influence on the recipient waterways through the following components:

- suspended and settleable matter
- oxygen consuming substances
- chlorinated substances
- colored substances
- nutrients (nitrogen and phosphorus)
- toxic substances
- pH

Emissions can be reduced through internal process modifications as they develop and/or through external effluent treatment.

Similarly, the mills will have an impact on the atmosphere as well as on the land mass through the following emissions:

- particulates (dust, sulphates, carbonates)
- sulphur dioxide
- carbon monoxide
- carbon dioxide
- reduced sulphur compounds (hydrogen sulphide, dimethyl sulphide, dimethyl disulphide, methyl mercaptan)
- organic compounds (alcohols, terpenes)
- chlorinated organic compounds (chloroform)
- chlorine and chlorine dioxide
- nitrous oxides

These emissions are also controlled by means of internal process control as well as through external treatment. Currently available external control equipment includes electrostatic precipitators, wet scrubber systems, filters (similar to bag houses) etc.

Meeting today's stringent environmental/ecological requirements in order to preserve the environment presents a challenge to almost every pulp mill in the Western world.

In many countries the emissions mentioned above are regulated by authorities, either through generally imposed limits and/or through specific limits applicable to a particular mill with consideration given to local conditions.

The crucial issue in the ALPAC project is considered to be the discharge of AOX. Internationally, a few countries have introduced limits in AOX. Table 3-1 shows the present legislation for these countries.

TABLE 3-1
Legislation on Discharge of Chlorinated Organic Substances from Pulp Mills

Country/ Province	Year Legislation takes effect	AOX-limit kg/ADt
Australia	1990	1.0[1]
Canada		
B.C.	1991	2.5
	1994	1.5
Ontario	1991	2.5
	1993	1.5
Quebec	1993	1.5
Finland	1995	1.4
Germany (FRG)	1990	1.0[2]
Norway[3]	1992	4.0
	1993	2.5
	1995	2.0
Sweden	1990	1.4–2.2[4]
	1992	1.5[4]

---

1) Only applicable for new hardwood kraft pulp mills
2) So far this has only been applied to sulphite mills, since no kraft mill is currently operational in FRG
3) Applicable to one kraft mill only with AOX discharge
4) Measured as total organic chlorines (TOCl) (AOX is about 1.2 - 1.4 times larger than TOCl)

Recent studies showing the poor relationship between AOX and harmful substances at AOX-levels below about 2 kg/ADt (described in detail in Chapter 4.3) are presently making the relevancy of this legislation questionable. The Swedish government previously announced that the AOX discharge limits for mills will gradually be reduced to 0.1 kg/ADt by the year 2010; however no decisions further to those reflected by Table 3-1 have yet been taken.

For BOD, which is also of concern in the ALPAC project, there are great variations in the regulations both internationally and nationally, depending on local conditions. For instance, in Sweden the BOD_7 limit varies between 8 and 20 kg/ADt for the kraft mills and in Finland this limit varies between 2.5 and 50 kg/ADt.

3.3
The Proposed Development

ALPAC has presented emission levels that the proposed mill would be designed to meet. In general terms, the limits presented are very low.

For BOD_5, ALPAC have indicated an emission level of 1.5 kg/ADt, which is only 50 % of the discharge level for other mills along the Athabasca River operating under the most stringent discharge limits. Furthermore, ALPAC has expressed their willingness to ensure that the DO content in the Athabasca River would not be influenced by the mill during periods when the DO level is below a critical level. One method of achieving this is by adding liquid oxygen to the water, if necessary.

For AOX, ALPAC's proposal implies a formation of about 2 kg AOX/ADt in the bleach plant. Biological external treatment would reduce this level to approximately 1.3 kg AOX/ADt. ALPAC has also proposed methods of further reducing this level. However, the methods remain undisclosed. Possibilities for reducing the AOX discharge below the 1.0 kg/ADt are discussed briefly under heading 4.3 below.

4
THE BLEACHED KRAFT PULP MILL PROPOSED BY ALBERTA PACIFIC FOREST INDUSTRIES INC.

4.1
General

Alberta-Pacific Forest Industries Inc. (ALPAC) are proposing to build and operate a green-field mill, producing bleached kraft pulp from softwood and hardwood. Plans include the production of paper at a later date.

The size of the proposed mill in terms of nominal production capacities is summarized by Table 4-1.

TABLE 4-1
Nominal Capacity Data for the Proposed Mill by Alberta-Pacific Forest Industries Inc.

Annual production (345 days/annum (d/a))	496,250 ADt
– hardwood pulp (260 d/a)	390,000 ADt
– softwood pulp (85 d/a)	106,250 ADt
Daily production (345 d/a)	
– hardwood pulp (260 d/a)	1,500 ADt
– softwood pulp (85 d/a)	1,250 ADt
Raw water supply	
– per second	1,55 m^3/s
– per day	134,000 m^3/d
Water returned to the river	90 %
– as clean cooling water	45 %
– as treated effluent	55 %

The site selected for construction of the mill is approximately 50 km downstream of the Town of Athabasca. The mill water supply would be taken from the Athabasca River. At present, there are no other mills located further downstream of the proposed ALPAC mill.

The environmental impact assessment for the proposed mill was published in May 1989 by ALPAC (ALPAC, 1989a and ALPAC 1989b). The environmental impacts of the mill were reviewed during autumn 1989, and the review report was submitted in February 1990 (ALPAC 1990). As a result of the review process a large number of documents were submitted describing different aspects of the impact of the mill.

The raw materials for the mill will consist primarily of aspen poplar, with up to 15 % balsam poplar as hardwoods. Softwoods will be predominantly white spruce; however, some jackpine, black spruce and balsam fir will also be used.

4.2
Pulping Technology

The mill will be based on the kraft process, which is a chemical process for making pulp from fibrous material, like wood. The kraft process has been practised for more than 100 years and is by far the most common pulping process used today.

The kraft process is based on a treatment of wood chips at elevated temperature and pressure (cooking). The chemicals used are sodium hydroxide and sodium sulphide with high alkalinity. The liquor with these chemicals is called white liquor. The chemicals react with the lignin substance in wood, making dissolution of the lignin into the alkaline liquor possible. Removal of lignin from the wood makes defibration into pulp possible with little or no mechanical action.

The reactions taking place between the chemicals in the cooking liquor and the wood substances are very complex, but quite well known. In addition to the lignin, cellulose and hemicelluloses in the wood react with the cooking chemicals. To avoid serious degradation of the cellulose, thereby making a pulp of inferior strength, the cooking processes have to be quenched before all lignin has been completely removed. The remaining lignin has to be removed by other means.

Developments during the 1980s have made it possible to remove more lignin during the cooking process than was previously possible. This technique is known as modified cooking (or extended cooking) (Johansson, et al. 1984). Through modified cooking the residual lignin can be lowered by 20 to 25 %, and in the near future perhaps by as much as 30 %. This implies that less lignin has to be removed in the bleach plant and less bleach plant effluent will be discharged.

The kraft process yields a relatively dark brown pulp, the color originating from residual lignin. To make the pulp suitable for printing and other purposes the pulp is subjected to different bleaching processes.

During the kraft cooking process some sulphide compounds with a strong and unpleasant odor are formed. These compounds are usually grouped under the heading total reduced sulphur, or simply, odorous compounds. Apart from the unpleasant smell, these compounds are not known to cause other problems and their toxicity level is (apart from hydrogen sulphide) low.

These uncondensible compounds are then collected from the digester area and incinerated together with uncondensible gases from other mill departments. There are several efficient ways to handle the incineration, as indicated below under the heading "4.4 / Recovery of Chemicals".

During the cooking process, some methanol is released and evaporated together with some of the extractive compounds. Because of their low quality due to impurities these substances are usually incinerated together with the odorous compounds. These should not cause any environmental problems.

After cooking, the pulp is washed to remove any dissolved material and chemicals. The removal of this material is important for recovery of the chemicals, for production of steam, and to avoid having the dissolved wood substances combined with the effluent. However, with the inclusion of an oxygen delignification stage, and because of the counter-current flow strategy, the washing after the oxygen stage is more important than the washing before the oxygen stage because the former is significant only in realizing a low carry-over of organic substances into the bleach plant.

The pulp is also screened after cooking, to remove impurities and any improperly cooked material. The materials rejected from the screen room are either recycled to the digester for recooking; removed for separate refining and returned for further processing; or are removed for combustion. An efficient removal, followed by recooking of uncooked material is recommended, since these particles contain more lignin than the proper pulp. If these particles remain with the pulp more bleaching chemicals will be required than for proper bleaching ordinary pulp. This results in the formation of more chlorinated organic substances than from acceptable pulp.

Since the oxygen delignification stage is incorporated into the chemical recovery cycle it can be viewed as separate from the bleaching processes that are not in a closed cycle. It provides another means for reducing the lignin content of the pulp before it is sent to the bleach plant. The residual lignin in a pulp is usually presented in terms of the kappa number, which is simply a number resulting from a standardized analysis procedure. Conventionally, cooking of softwood bleachable-grade pulps used to be terminated at a kappa number of 32; however, with modified cooking the pulp can be delignified to a kappa number of 24. Using the oxygen delignification process more than about 40 % of the residual lignin can be removed, yielding kappa numbers in the range of 12-14 in softwood pulp. For hardwoods, which are easier to delignify, it is now possible to achieve a kappa number of 8 for pulp entering the bleach plant.

An important characteristic of the oxygen delignification process is that it has essentially no direct interaction with the environment since no gases or effluents are released.

After the oxygen delignification stage the pulp is washed to remove and recycle as much of the active and dissolved chemicals as possible. Since any dissolved organic substance entering the bleach plant may react with the chlorine compounds it is highly desirable to reduce such material in the pulp.

ALPAC is proposing to use a table washer in this position, as illustrated by Figure 2.5 in the Main Report (ALPAC 1989a). Wash liquor will be in the form of condensate from the evaporation plant. The wash liquor will run countercurrent, back through the plant for recovery of chemicals. At a final open wash stage (Figure 2.5 in the Main Report) warm water is used with the filtrate going to the general sewer. This is a recommendable way to reduce the dissolved organic compounds in the pulp to a minimum before it reaches the bleach plant. The filtrate to the sewer contains some BOD. Without the open wash stage this BOD material would enter the bleach plant, become partially chlorinated, and then be discharged with the effluent.

For the brown stock washing, the addition of defoamer is indicated in Figure 2.5 of the Main Report (ALPAC 1989a). Some defoamers are known as potential precursors for the formation of chlorinated dibenzo-*p*-dioxins and dibenzofurans in the bleach plant (Voss et al. 1988).

4.3
Bleaching Technology

4.3.1
Recent Development and Achievements

The purpose of bleaching is removal of the remaining lignin in the pulp as well as to eliminate some of the impurities in the pulp. The bleached pulp should preferably have a high brightness, a low content of impurities (such as bark, resin particles, shives and knot particles), and a high brightness stability.

For the most part the bleaching processes are carried out in sequences using inorganic chlorine chemicals; but to an increasing extent other substances (primarily oxygen and peroxide) are being used. A conventional sequence for kraft pulp has been the CEHDED sequence (see Table 4-2 for definitions of the alternate sequences and Appendix II for abbreviations), with a small amount of chlorine dioxide added to the first stage. Using this sequence the total charge of active chlorine in the bleach plant was around

90–110 kg per ton of pulp (90 %, air dry ton (ADt)) for conventional unbleached kraft pulp.

During the 1980s attention was drawn to the negative environmental impact of the bleach plant effluents. This concern resulted in the development of new bleaching procedures with much less discharge of effluents.

The issue connected with bleach plant effluents that was and still is being addressed is the formation of chlorinated organic substances (measured as AOX or TOCl). Of particular concern was the demonstrated formation of chlorinated dioxin and furan compounds.

Efforts to reduce formation of these compounds resulted in several new discoveries, apart from those mentioned under the heading "4.2 / Pulping Technology".

In Sweden, substantial time and effort has been spent on studies of bleach plant effluents and their biological effects. These studies were financed by the Swedish Forest Industries' Water and Air Pollution Research Foundation (SSVL). The most recent of their projects, "Environment 90" carried out from 1986–1990, gave an environmental ranking to a number of bleaching processes, both with and without external treatment (Stroemberg et al. 1990). This ranking is shown in Table 4–2.

TABLE 4–2
Ranking of some bleaching processes for softwood kraft pulp in order of decreasing environmental impact (top to bottom). Extended cooking is not considered.

Process (+ treatment)	Comment
(C90D10)EHDED	–
(C90D10)EHDED	– Improved washing compared with traditional technique
(C90D10)EHDED + UF E1	– Ultrafiltration of El–effluent
O(C85+D15)EDED	– Oxygen bleaching to kappa number 20 plus washing to 10–12 kg/ADt as COD
(C90D10)EHDED + UF E1+Z	– Ozone treatment of permeate and C–stage effluent
O(C85+D15)EDED	– Oxygen bleaching to kappa number 20 plus washing to 4–6 kg/ADt as COD
(C90D10)EHDED + aerated lagoon	– Mill effluent treated in an aerated lagoon
(C90D10)EHDED + ion exchange	– Ion exchange of total bleach plant effluent
(D85C15)EDED	–
O(C85+D15)EDED + aerated lagoon	– Oxygen bleaching to kappa number 20
O(D85+C15)EDED	– Oxygen bleaching to kappa number 17

It is apparent from Table 4-2 that a high proportion of chlorine dioxide (D = ClO_2) in the first stage of bleaching is favorable. This is due to several reasons.

First, a replacement of elemental chlorine (C = Cl_2) with chlorine dioxide (D = ClO_2) reduces the formation of AOX. Actually, chlorine dioxide only yields about one fifth as much AOX as elemental chlorine at the same charge of active chlorine. The total AOX or TOCl formation is so strongly related to the charge of chlorine compounds that it can be expressed by the following equation (Germgaard and Larsson 1983, Earl and Reeve 1989).

$$AOX = 0.1\ (C + D/5 + H/2)$$

where AOX becomes expressed as kg/ADt. C, D and H are expressed as charge of active chlorine per ton of pulp. The AOX analysis usually gives a value that is somewhat higher than the TOCl analysis (EIA 1990, Axegaard et al. 1988).

To give a frame of reference, Table 4-3 below shows some characteristics for an "old" bleaching sequence versus a "modern" one.

TABLE 4-3
Process Characteristics for the "1970" Bleaching Technique and a "Modern" Bleaching Alternative for 1990

	"1970"	"1990"
Bleaching-sequence	CEHDED	O(D25,C70+D5)(EOP)D(EP)D
Kappa number of unbleached pulp	35	20
Charge of active chlorine (kg/ADt):		
C = Cl_2	60–80	20
H = HOCl	10–15	-
D = ClO_2	25–35	30
AOX from bleach plant (kg/ADt)	8–9	2.1

Definitions for the symbols are given in Appendix IV.

TOCl or AOX is a very coarse measure of the total amount of chlorinated organic substance. Recent studies have focused more on specifically recognized chlorinated substances in bleach plant effluents. These specific compounds also include those considered to be the most toxic of the effluent substances.

Secondly, chlorine dioxide yields less chlorine substitution in each organic molecule than chlorine does. Whereas chlorine yields tri– and tetra–chloro–substituted compounds, chlorine dioxide yields very little or no such degrees of substitution. The formation of highly toxic dioxins and furans is a major concern, when elemental chlorine bleaching is used. However, with the use of about 50 % chlorine dioxide in the first bleaching stage there are no detectable dioxins or furans in the effluent.

Thirdly, reinforcement of the first alkali stage with oxygen and peroxide and with increased temperature has made a reduction of total charge of active chlorine in the bleach plant possible. In addition it has made a reduction of the charge of active chlorine in the first bleaching stage (the chlorine multiple) possible, thereby further reducing the formation of AOX. As shown below, some specific chlorinated compounds are actually reduced much more than AOX when the chlorine multiple is decreased. This technology became available as late as during 1988 (Dillner et al. 1989, Sjoeblom amd Hardmeier 1988).

Fourthly, a good chemical mixing through high–shear mixing has also been an important step in reducing the amount of effluent from the first bleaching stage (Tibbling 1988). This is important for avoiding local over–chlorination, which contributes to high chlorine substitution of organic molecules. Moreover, medium consistency bleaching at about 10% pulp consistency in the first stage also results in decreased requirement of active chlorine.

Fifthly, sequential (multiple) charging of chlorine dioxide and chlorine decreases the total requirement of active chlorine.

It is important to emphasize that with "modern" bleaching technology the chlorine substituted compounds that are regarded as being the most harmful to the environment are reduced much further than the total AOX. This fact is illustrated below by Figures 4/1 – 4/6 (Axegaard 1988a: Axegaard 1989; Berry et al. 1989; Wrist 1990). In Figures 4/1, 4/2, 4/3, 4/5 and 4/6 the Cl_2–multiple refers to the charge of elemental chlorine per ton of pulp per kappa number (elemental chlorine multiple = (kg Cl_2)/(10 * ADt * kappa number). For instance, an elemental chlorine multiple of 0.10 corresponds to a charge of 20 kg Cl_2 per ton of pulp, for pulp having a kappa number of 20. In Figure 4/4 the active chlorine multiple refers to the charge of active chlorine per ton of pulp per kappa number, *i.e.* chlorine dioxide is included in this factor.

FIGURE 4/1
The Formation of Tri– Plus Tetrachloroguaiacols *versus* the Elemental Chlorine Multiple in Bleaching Stage 1. The Active Chlorine Multiple for Stage 1 was 0.20.

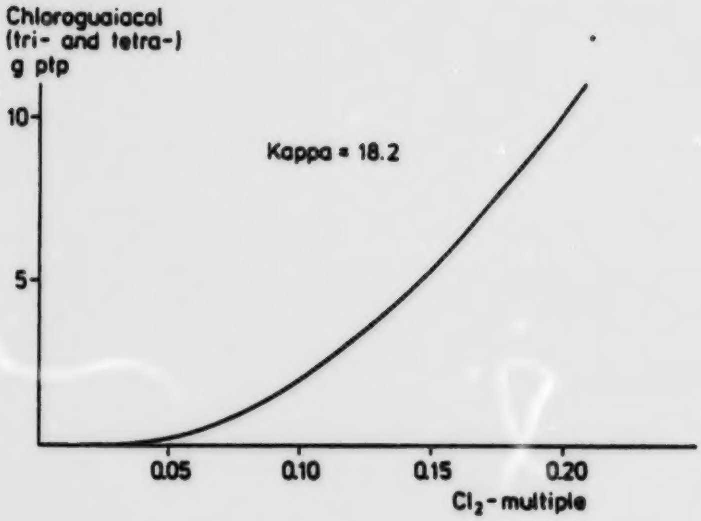


FIGURE 4/2
The Formation of Di–, Tri– and Tetrachloroguaiacols *versus* the Elemental Chlorine Multiple in Bleaching Stage 1: (a) For a Pulp with Kappa Number 18.2 and with an Active Chlorine Multiple of 0.20; (b) Formation of Tetrachloroguaiacol for Pulps from Different Sources.

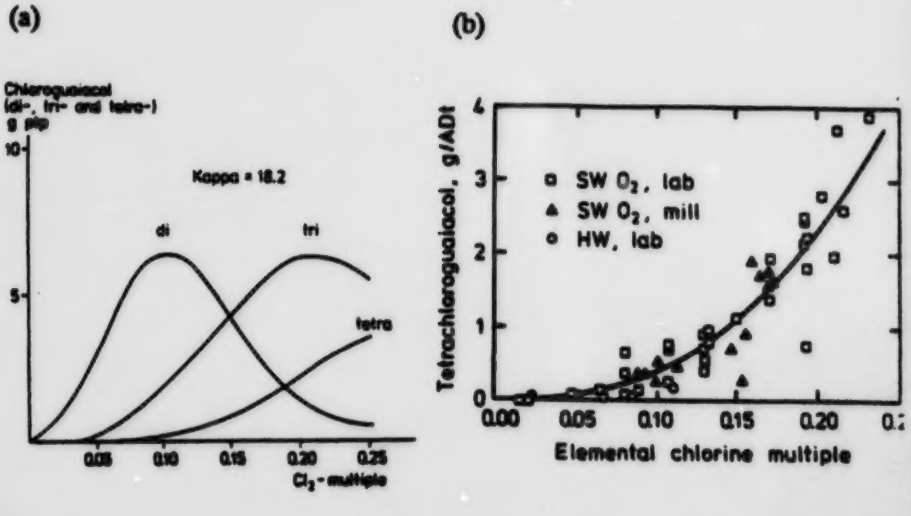


FIGURE 4/3
The Formation of Di–, Tri– and Tetrachloroguaiacols for (g/ADt) Pulps of Different Kappa Numbers *versus* the Elemental Chlorine Multiple in Bleaching Stage 1. The active chlorine multiple for stage 1 was 0.20.

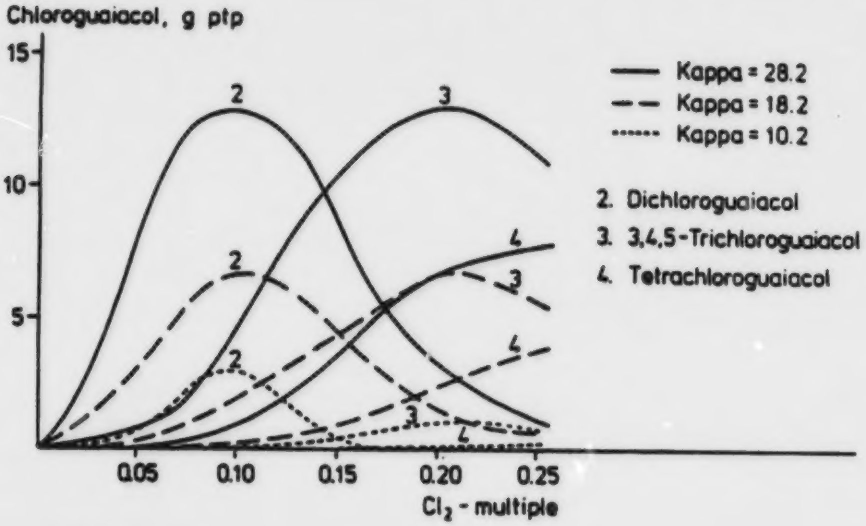


FIGURE 4/4
Tetrachloroguaiacol (g/ADt) in Effluent from Softwood Bleaching against Active Chlorine Multiple and Degree of Chlorine Dioxide Substitution

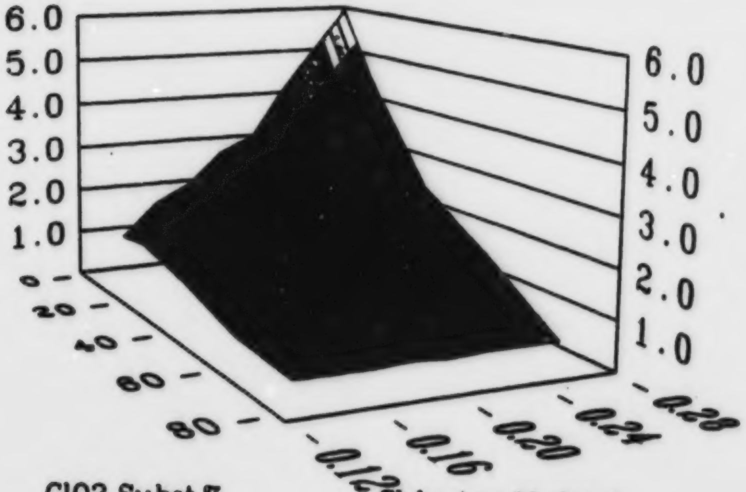


FIGURE 4/5
The Formation of Chloroform, $CHCl_3$ (g/ADt), *versus* the Elemental Chlorine Multiple in Bleaching Stage 1

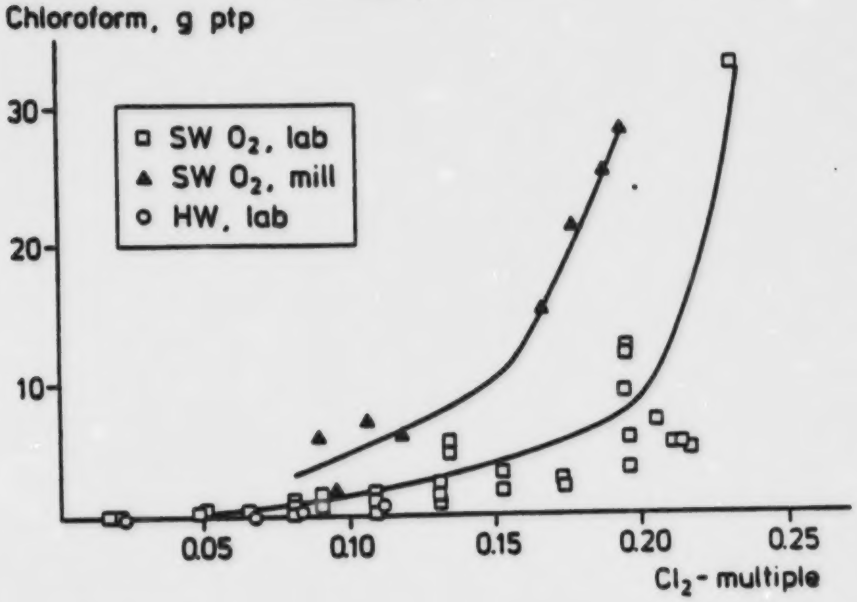
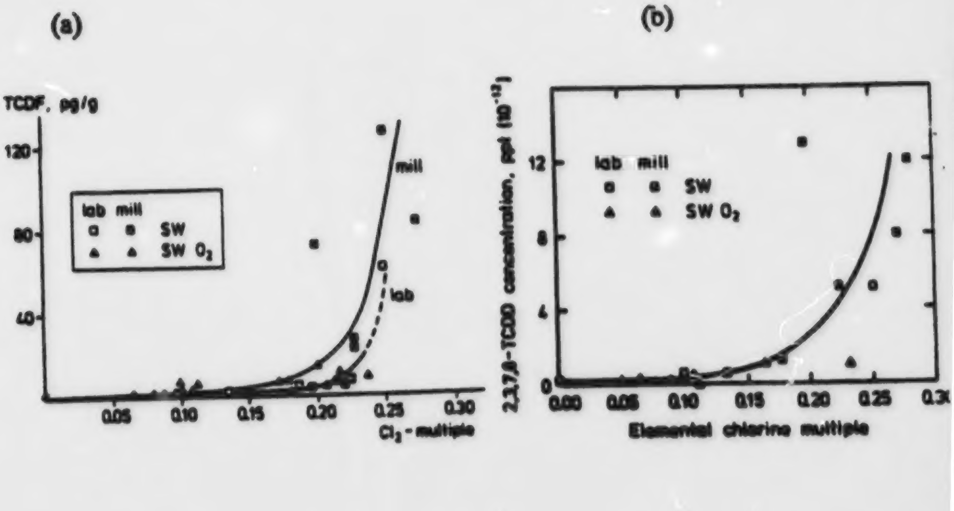


FIGURE 4/6
The Total Amount of (a) 2,3,7,8-Tetrachlorodibenzofuran (TCDF) and (b) 2,3,7,8-Tetrachlorodibenzo-*p*-Dioxin (TCDD) Being Formed *versus* the Elemental Chlorine Multiple in Bleaching Stage 1.



Biological studies on the toxicity of the bleach plant effluents from modern bleaching processes have shown parallel results, that the decrease in chlorinated organic compounds formed as illustrated in Figures 4/1 to 4/6 in a rapid decline in effluent toxicity. Figure 4/7 (following) illustrates the combined effect of several different toxins that have been added together in proportion to the individual toxicities shown in Table 4–4 (Wrist 1990).

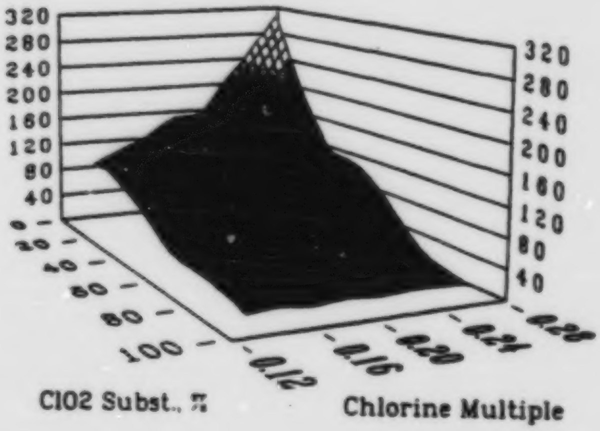
TABLE 4–4
Toxicity Equivalency Factors (TEF) for Chlorinated Phenolic Compounds Based on Estimates of Chronic Toxicity. The Scale Has Been Proposed by Dr. Willes of Cantox.

Degree of chlorination of phenolic compound	TEF value
Monochloro–	0.002
Dichloro–	0.01
Trichloro–(1)	0.05
Tetrachloro–	0.5
Pentachloro–	1.0

---

(1) 2,4,6–Trichlorophenol has been assigned the highest TEF value of 1.0.

FIGURE 4/7
Total Toxicity Equivalency Units for Several Different Chlorinated Phenolic Compounds (Based on Estimates of Chronic Toxicities and Calculated from Table 4–4) Against Active Chlorine Multiple and Degree of Chlorine Dioxide Substitution



Figures 4/8 and 4/9 show the chronic toxicities against varying AOX formation at an active chlorine multiple of 0.24 (Wrist 1990). The chlorine dioxide substitution for chlorine is shown as the parameter that creates the various AOX formations. In parallel with the results indicated Figures 4/1–4/6, Figures 4/3 and 4/9 illustrate that the chronic toxicity is reduced much more readily than AOX with "modern" bleaching technology. For instance, Figure 4/8 shows the chronic toxicity before the effect biological treatment of the effluent is included. When the AOX formation is reduced from 6 to 2 kg/Adt (3 times), the chronic toxicity is reduced from 250 to about 10 units (25 times). On Figure 4/9, the effects of biological treatment are shown and the lines with arrowheads connect points of equivalent chlorine substitution on the chronic toxicity curves before and after biological treatment. The biological treatment lowers the chronic toxicity an additional 2 to 2.5 times. The anticipated levels of ALPAC and a conventional pulp mill for AOX and toxicity are shown in Figure 4/9.

FIGURE 4/8
Total Chronic Toxicity Equivalency Units *versus* AOX Formation at an Active Chlorine Multiple of 0.24. Chlorine Dioxide Substitution is Varied from 0 % to 90 % and is Shown as a Parameter at each Point in the Diagram.

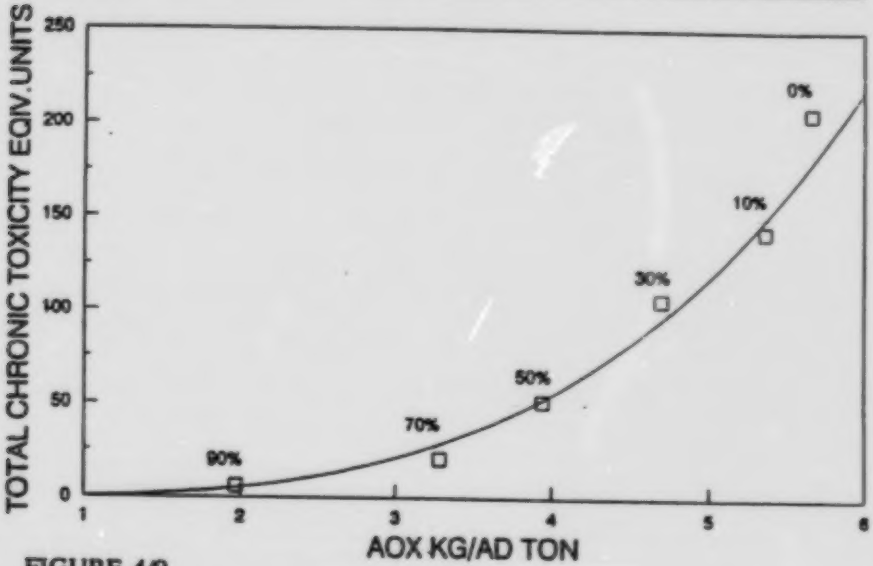
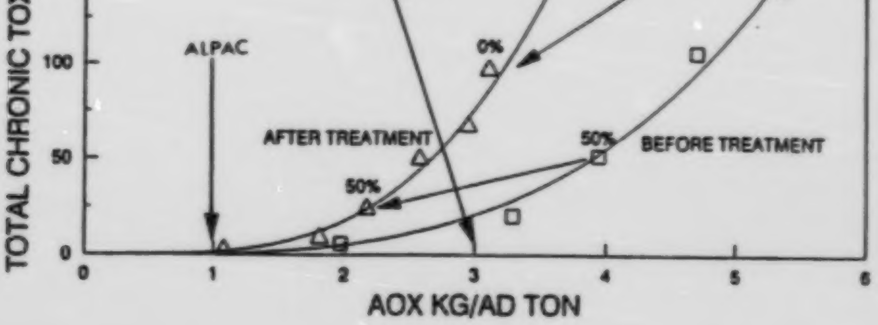


FIGURE 4/9
Total Chronic Toxicity Equivalency Units *versus* AOX Formation at an Active Chlorine Multiple of 0.24. Chlorine Dioxide Substitution is Varied from 0 % to 90 % as in Figure 4/8. The Effect of Biological Treatment is also Illustrated.



Another consequence of modern bleaching technology is illustrated in Figure 4/10, where extractable organic halides (EOX) are shown, *versus* the total AOX (Axegaard 1988b; Earl and Reeve 1989). The EOX is expected to measure compounds with bio-accumulating tendency more correctly than AOX. The figure shows that for AOX levels below 3 kg/ADt the EOX levels becomes negligible.

FIGURE 4/10
Formation of Heptane Extractable Organic Halides (EOX) *versus* Formation of AOX in the C + E Stages (see Appendix II for definitions). Open Symbols Refer to C(100 %)E-bleaching while Closed Symbols Refer to (D50C50)E-bleaching. To Achieve Different AOX formation the Active Chlorine Multiple was Varied from 0.35 down to 0.10. (The Pulp Used in this Experiment was a Softwood Kraft Pulp with Kappa Number 30.)

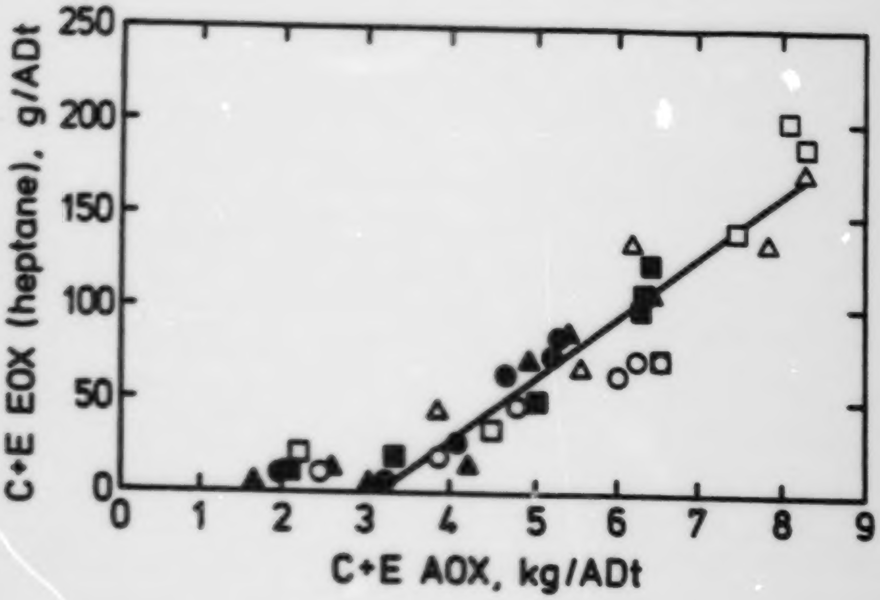
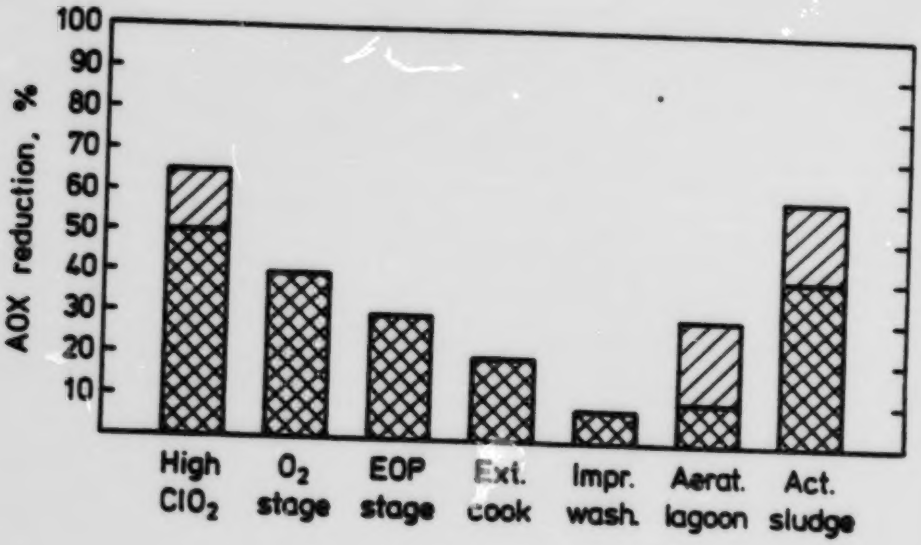


Figure 4/11 provides a summary of the different new available techniques for AOX-reduction by illustrating the potential levels for reduction through different measures (Sjoeblom and Mjoeberg 1990). In this figure each measure is considered by itself against a conventional bleached pulp, where AOX formation was 8–9 kg/ADt (for softwoods). When using more than one measure the effects must be multiplied to get an estimate of the potential AOX reduction. In the figure, some biological treatments are also included for comparison. These external treatment methods will be briefly described below, under heading "4.5 / Waste Water Treatment".

FIGURE 4/11
Potential AOX Reduction Levels Achievable Through Different new Techniques Relative to the Conventional Kraft Bleaching Process, with 8-9 kg AOX/ADt for Softwoods.



4.3.2
Bleaching Technology of ALPAC

ALPAC has proposed to take advantage of many of the findings described under heading "4.3.1 / Recent Development and Achievements". Thus, an oxygen delignification stage would be included and the bleaching sequence would be (DC) (EO) DED, employing as much as 70 % chlorine dioxide substitution in the first stage. A multiple chemical addition system would also be used in the first stage, where chlorine dioxide is added first. This will further reduce the negative impact of elemental chlorine by decreasing the consumption of this chemical.

With this technology ALPAC anticipates reaching an AOX level of 1.4 kg/ADt from the processes, and a level of 1.0 kg/Adt after biological treatment. Hardwoods are somewhat easier to pulp and bleach than softwoods, but the proposed emission levels would be very low by international comparison. The anticipated level of AOX at ALPAC is shown on Figure 4/9 where it can be compared to a more conventional bleach kraft mill producing approximately 3.0 kg AOX/Adt.

4.3.3
Newer Bleaching Technologies

There are some further means for reducing the AOX load (Sjoeblom and Mjoeberg 1990). First, a comparatively low cost modification involves the reinforced alkali stage. In this process the temperature is raised, the vessel (or a small up-flow tower) is pressurized, and peroxide is added. As described above, this allows for a reduction of the active chlorine multiple down to levels where formation of poly-chlorinated substances is negligible.

Secondly, the degree of chlorine dioxide substitution can be increased to 100 % for hardwoods and 85–95 % for softwoods. Chlorine dioxide is a more expensive chemical than elemental chlorine, and increased usage would add significantly to production costs. Experience with such high levels of chlorine dioxide is limited; however, along all other measures it should be possible to reach market pulp quality levels: brightness and pulp strength being the crucial parameters. For softwoods, the feasibility of attaining a 90 % brightness with 100 % chlorine dioxide in mill operations is not yet fully proved.

With these further process modifications one can estimate a reduction of AOX formation from 1.8 to about 1.2–1.5 kg/Adt. After biological treatment the AOX discharge would be 0.6–0.8 kg/Adt. Further reductions of the AOX discharge may be possible by pushing the "new" technologies further. However, such procedures are not proven technology and will endanger the pulp quality, especially the strength properties. For a market pulp the pulp quality is crucial, especially in a depressed market situation. Other new means for reducing AOX discharge that have been investigated, like for instance ultrafiltration, can neither be regarded as proven technology. The costs (investment as well as operational) for such special treatments are also presently so high that they are not acceptable for the present pulp market.

Once again, it should be pointed out that in a "modern" bleach plant the formation of poly-chlorinated substances will be reduced much more than the reduction of AOX, when compared to a conventional bleach plant.

4.4
Recovery of Chemicals

In the kraft process the waste liquor (black liquor) from the pulping processes contains all the dissolved organic substances and the residuals of the active cooking chemicals (sodium and sulphur). The organic substances in the black liquor are used for heat production through combustion and the inorganic cooking chemicals are regenerated through the recovery cycle.

The filtrate from the pulp washing is quite diluted and to make it combustible the concentration of the liquor has to be increased. This is achieved in the evaporation plant, where the dry solids concentration of the liquor is increased to above 60 %.

In the evaporation process both odorous compounds and methanol, which has a low boiling point are vaporised. These gases have to be properly incinerated so as to handle the odor problem of the kraft mill in an acceptable way.

After the evaporation process the thick black liquor can be burnt in the recovery boiler. The heat is used to produce large quantities of steam. Inorganic chemicals are collected in the bottom of the furnace as a smelt, and are withdrawn into a smelt-dissolving tank for further reactions.

The emissions from the recovery boiler consist of those materials emitted with the flue gases. These consist of sulphur dioxide and particulate material, and to a small extent, hydrogen sulphide. The hydrogen sulphide emission must be controlled but should not cause any serious problems. The particulate emission is controlled by means of electrostatic precipitators. The sulphur dioxide emissions depend on sulphidity and sulphur make-up, as well as on combustion conditions. Sometimes a scrubber is required to keep the sulphur dioxide emissions from the stack at acceptable levels.

In remaining parts of the recovery cycle the only source of environmental concern is the lime kiln, where calcium carbonate (lime) is converted into calcium oxide. The emissions from the kiln consist of particulates along with the flue gases, and are cleaned through electrostatic precipitators. The flue gas content of harmful gases is usually small since these gases are absorbed by the lime. Sometimes, total reduced sulphur can be of concern.

4.5
Waste Water Treatment

In the Main Report (ALPAC 1989a) ALPAC proposed to treat the effluent first through a primary clarifier system and then through a secondary aerated lagoon system.

As a biological treatment system aerated lagoons have certain advantages over activated sludge treatment plants but in cold climates the level of activity in a lagoon may decrease due to low temperatures.

Furthermore, activated sludge treatment plants usually yield better results for BOD as well as AOX in terms of reductions.

ALPAC has also changed the concept to an activated sludge plant as documented by the Pre-Design Report of November 1989 (ALPAC 1989c, Stanley Assoc. Eng. Ltd. 1989).

Average retention times in activated sludge plants range from 10 hours for high load units to 24 hours for low load units. ALPAC is proposing more than 24 hours retention time; this indicates a well sized treatment plant.

The design data for the external effluent treatment system are summarized in Table 4-5 below. In the effluent treatment plant pre-design report (ALPAC 1989c, Stanley Assoc. Eng. Ltd 1989) it is proposed that phosphorus and nitrogen be added as nutrients for the biological processes. Phosphorus, in particular, may contribute to the eutrophication of the river basin. A major part of the phosphorus will follow the sludge for combustion. Some, however, will leave the plant with the treated effluents. (In Sweden the phosphorus discharges with effluents from mills varies between 40 and 140 g/ADt.)

TABLE 4-5
Design Data for the Proposed Effluent Treatment Plant of Alberta-Pacific Forest Industries Inc.

Design flow	1000 L/s
Before treatment	
BOD_5 load	37,500 kg/d (25 kg/ADt)
TSS load	39,000 kg/d (26 kg/ADt)
Color load (Pt-Co Color Units)	63 t/d (42 kg/ADt)
COD load	84,000 kg/d
AOX load	3,200 kg/d (2.1 kg/ADt)
After treatment	
BOD_5 discharge	2,250 kg/d (1.5 kg/ADt) (27 mg/L) (94 % removal)
TSS discharge	4,500 kg/d (3 kg/ADt) (55 mg/L) (88 % removal)
AOX discharge	< 1,950 kg/d (1.3 kg/ADt) (22 mg/L) corresp. 1,500 kg/d (29 % removal minimum, up to 60 % removal maximum)
Phosphorus (P) discharge	< 1 mg/L (< 86 kg/d) (<58 g/ADt)

The raw water pipeline is scheduled to pass underground, along the Nova Gas Pipeline, through the Pine Sands Natural Area, as shown in Figure 2.2 of the Main Report (ALPAC 1989a). To protect this rather unique natural area, a reinvestigation of possible alternatives is recommended.

4.6
Air Pollution Control Technology

The different emissions to the air from pulp can be classified by

- particulate emissions (i.e., from lime kiln, power boiler, recovery boiler)
- odorous gases (including hydrogen sulphide) and methanol (from digester plant, evaporation plant and tanks)
- sulphur dioxide (from recovery boiler, incineration furnace).

Particulate emissions are usually controlled by means of electrostatic precipitators. Textile filters in bag houses are more sensitive and are not frequently used for pulp mill applications.

The systems used for handling and incinerating odorous gases and methanol have been described in the foregoing text. To avoid disturbances during incineration, the use of separate furnaces with small boilers attached to them is recommended. Some back-up system is necessary in case of upsets. For this purpose, an incineration in the lime kiln or a simple torch is often used.

In addition the weak (low concentration) odorous gases from various liquor tanks should preferably be collected and incinerated. Often these gases are mixed with the secondary air for the boilers.

Sulphur dioxide in flue gases is often collected by means of scrubber systems. The scrubber liquor used in the process can be oxidised white liquor or simply an alkali solution.

It has been proposed that the sludge from the external treatment be incinerated in a bark boiler after dewatering. The moisture content of the sludge would be quite high, thereby making combustion poor. If the power boiler is used for incineration the emissions should be carefully monitored and compared when as opposed to when not incinerating the biosludge.

The sludge would also contain chlorides. Since it is established that chlorinated dioxins can be synthesised in flue gases at temperatures between 200°C and 500°C, when chlorides are available (Dioxin '89), one should avoid incinerating sludge in such a way. The reactions probably take place between soot and inorganic chloride in the presence of fly ash in the flue gas duct (Dioxin '89).

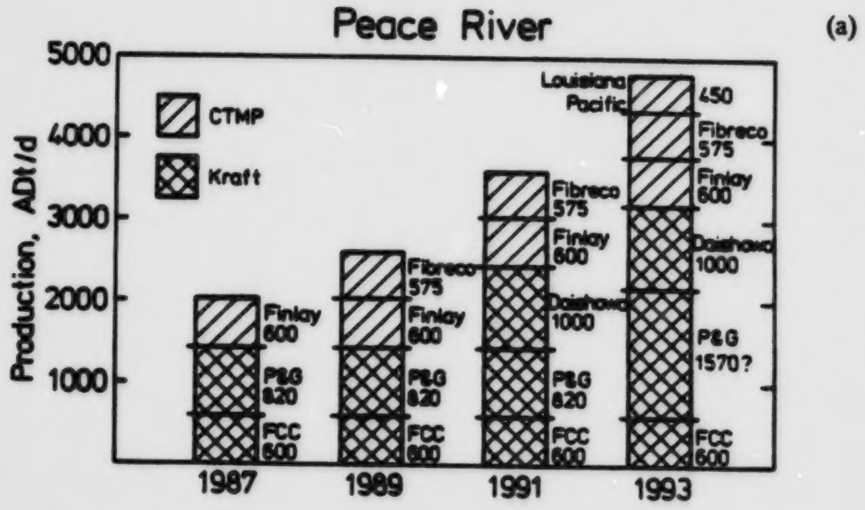
Other available alternatives would simply be landfilling or incinerating the sludge in a small dedicated furnace and thereafter cooling the flue gases rapidly to temperatures below 200°C.

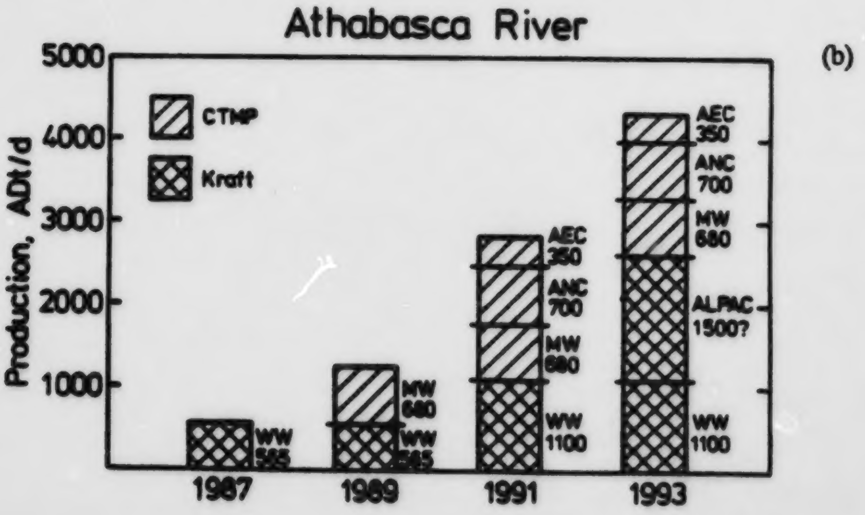
5
PRESENT POLLUTION LOADINGS AND ESTIMATED FUTURE EMISSIONS

5.1
General

Since 1985 there has been a substantial growth in the pulp industry along the Peace and the Athabasca Rivers. It seems that this expansion has taken place without any long term development plan for environmental protection for these regions. Figure 5/1 illustrates the recent expansion in pulp production as well as the anticipated expansion along the two rivers.

FIGURE 5/1
Pulp production data for pulp mills along the Peace and the Athabasca Rivers in British Columbia and Alberta. (a) Peace River, (b) Athabasca River





When considering the environmental impact from the mills there is a big difference between the mechanical (TMP and ground wood) and chemimechanical (CTMP) mills as compared to the chemical kraft mills with bleach plants.

Effluents from the mechanical and chemimechanical mills operate at pulp yields of 90–95 % and primarily contain organic matter from the wood. These substances are readily degradable in nature, thereby consuming oxygen. (As a reference, the BOD load from a CTMP mill with 90 % yield prior to effluent treatment would be about 40 kg BOD/ADt.) Environmental concerns arising from the effluents released from CTMP mills include the toxicity of resin compounds or extractives and the discharge of total suspended solids (TSS).

For kraft mills the BOD and TSS parameters are normally regulated; however in addition to those parameters an increasing amount of attention is being paid to the characteristics of the effluents from the bleach plants. This is due to the fact that these effluents contain a large number of different chlorinated organic compounds. Some of the compounds that have been identified are known to be highly toxic and some have bioaccumulating tendencies.

In the present review, the BOD load is only considered for the Athabasca River between Hinton and the Grand Rapids, since the aeration that takes place at Grand Rapids virtually nullifies any impact from the upstream mills. Thus, a new upstream mill would have negligible effect on the dissolved oxygen situation below the Grand Rapids.

However, the impact from all kraft mills along the two rivers would have to be considered for AOX and TOCl since some of these substances have a high stability in nature and will therefore have an impact on the major length of these two river systems. This issue is discussed in another chapter.

The BOD and AOX loads are of the primary concern in the present review. Other effluent parameters are not considered as crucial in relation to the ALPAC mill (ALPAC 1989a).

Table 5–1 provides some fundamental data for the other mills that are of importance in the present study.

The data in this table was taken from Alberta Environment Licenses, except for ALPAC which are from ALPAC 1989a and 1989c. The data for the Fletcher Challenge mill is from EIA 1990.

TABLE 5-1
Some Fundamental Data on the Mills Along the Athabasca River and on the Kraft Mills Along the Peace River

Mill	Year	Nominal production (ADt/d)	Total effluent (m^3/ADt)	Total effluent (m^3/s)
CTMP-mills along Athabasca:				
Millar Western at Whitecourt (MW)	1988 on	680	22	0.173
Alberta Newsprint Co. at Whitecourt (ANC)	1990 on	625-700	21-24	0.29
Alberta Energy Co. at Lesser Slave Lake (AEC)	1990 on	350	21	0.29
Bleached Kraft Pulp Mills:				
Weldwood at Hinton (WW)	to 1990	565 (SW)	ca 160	ca 1.0
	1990 on	1100 (SW)	103	1.31
Alberta-Pacific at Athabasca (ALPAC)	1993 (*) on	1500 (HW)	< 58	< 1.0
	1993 (*) on	1250 (SW)		
Fletcher Challenge at MacKenzie, BC (FCC)		600 (SW)		
Procter & Gamble to at Grande Prairie (P&G)	to 1993	820 (SW)	73	0.7
	1993 (?) on	1570 (SW/HW)		
Daishowa at Peace River	1990 on	900 (SW)		
	1990 on	1000 (HW)		

HW = Hardwoods
SW = Softwoods

* = proposed
? = planned

5.2
Licensed and Estimated Water Pollution from the Pulp Mills

5.2.1
General

The tables presented below under the heading 5.2 give selected data for the years 1987–1993. Data is based on Alberta Environment operating or construction licenses Alberta Environment 1990b), except ALPAC which is from ALPAC 1989c.

5.2.1
Biochemical Oxygen Demand (Athabasca River)

The specific mills along the Athabasca River are shown in Figure 4–1 in the report of the EIA Review Board (EIA 1990) and are also shown on Figure 2/1 and Figure 5/1 (b).

TABLE 5–2
BOD_5 from Effluent Discharges from Pulp Mills to Athabasca River (Alberta Environment 1990b)

		BOD_5, (kg/ADt)	
Mill	Year	Monthly Average	Daily Maximum
CTMP–mills:			
MW	1990	7.5	14.0
	1993	3.0	6.0
ANC	1990	3.0(1)	6.0(1)
	1993	3.0	6.0
AEC	1993	3.0	6.0
Bleached Kraft Pulp Mills:			
WW	1987		11.7
	1990	7.0(2)	11.0
	1993	3.0	6.0
ALPAC (proposed)	1993	1.5	3.0

---

(1) If Athabasca River flow is less than 17 m^3/s lower limits apply.
(2) If Athabasca River flow is less than 50 m^3/s lower limits apply.

5.2.2
Suspended Solids (TSS)

TABLE 5-3
Suspended Solids from Effluent Discharges from Pulp Mills to Athabasca River (Alberta Environment 1990b)

		TSS, kg/ADt	
Mill	Year	Monthly Average	Daily Maximum
CTMP-mills:			
MW	1990	30.0	40.0
	1993	5.0	10.0
ANC	1990	9.5	19.0
	1993	5.0	10.0
AEC	1990	NA	NA
	1993	5.0	10.0
Bleached Kraft Pulp Mills:			
WW	1987	NA	24.6
	1990	14.5	22.7
	1993	NE	NE
ALPAC (proposed)	1993		3.0

NA = Not Applicable
NE = Not Established

5.2.3 Color

TABLE 5-4
Color from Effluent Discharges from Pulp Mills to Athabasca River (Alberta Environment 1990b)

Mill	Year	Color, kg/ADt Monthly Average
CTMP-mills:		
MW	1990	45
	1993	45
ANC	1990	45
	1993	45
AEC	1993	45
Bleached Kraft Pulp Mills:		
WW	1987	350
	1990	182
	1993	NE
ALPAC (proposed)	1993	42

NE = Not Established

5.2.4
Resin Acids and Phenols

TABLE 5-5
Resin and Fatty Acids and Phenols from Effluent Discharges for 1990 from Pulp Mills to Athabasca River (Alberta Environment 1990b)

Mill	Resin and fatty acids		Total Phenols	
	(mg/L)	(kg/ADt)	(mg/L)	(kg/ADt)
CTMP-mills:				
MW	2.0	0.044	1.0	0.022
ANC	2.0	0.042	1.0	0.021
AEC	2.0	0.042	1.0	0.022
Bleached Kraft Pulp Mills:				
WW	2.0	0.206	0.252	0.026
ALPAC (proposed)	*	*	*	*

*) No value has been specified or proposed, but ALPAC intends to include these compounds in their monitoring program (ALPAC 1989a).

5.2.5
Nitrogen and Phosphorus

TABLE 5-6
Effluent Discharges of Nitrogen and Phosphorus for 1989 (not ALPAC) from Pulp Mills to the Athabasca River (Alberta Environment 1990b)

Mill	Nitrogen		Phosphorus	
	(mg/L)	(g/ADt)	(mg/L)	(g/ADt)
CTMP-mills:				
MW	56.5	1 242	32.6	716
ANC	56.5	1 180	32.6	681
AEC	56.5	1 180	32.6	681
Bleached Kraft Pulp Mills:				
WW	5.9	607	0.82	84
ALPAC (proposed)	4	230	1	58

5.2.6
Chlorinated Organic Substance (AOX or TOCl)

The formation of chlorinated organic substances is closely related to the processes practised in a mill. Table 5-7 shows the bleaching sequences for the mills being studied in this report.

TABLE 5-7
Pulping Processes for the Kraft Mills Along Athabasca and Peace Rivers

Mill	Year	Bleaching (2) Sequence	ClO_2 (3) Substitution	Extended Cooking
WW	1987	C_DEHDED	5-20 %?	No
	1990	O(DC)(EOP)DED	50-65 %	Yes
	1993	O(DC)(EOP)DED	70 %?	Yes
ALPAC	1993	O(DC)(EO)DED	70 %	Yes
FCC (B.C.)(1)	1987	C_DEHDED	5-20 %?	No
	1990 (1)			
	1993 (1)			
P&G	1987	C_DEHDED	10-30 %?	No
	1990	(DC)(EO)DED	~100 %	No
	1993	O(DC)(EO)DED	~100 %?	Yes
Daishowa	1990	O(DC)(EO)DED	70 %	Yes
	1993	O(DC)(EO)DED	70 %?	Yes

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(1) No information submitted.
(2) See Appendix II for list of abbreviations
(3) In the first chlorination stage

If actual measurements are not available the AOX discharge can be estimated from this information. This is described above under heading "4.3.1 / Recent Development and Achievements". Table 5-8 (following) shows these values but most of the data in the table are taken from on Alberta Environment licenses.

TABLE 5-8
Effluent discharges of chlorinated organic substance from pulp mills to Athabasca River and to Peace River (Alberta Environment 1990b estimated or assumed values by Jaakko Pöyry Oy)

Mill	Year	AOX, kg/Adt Monthly Average	AOX, kg/Adt Daily Maximum	
WW	1987	6.0	-	Estimated
	1990	1.5	3.0	A.E. license
	1993	1.5	3.0	A.E. license
ALPAC (proposed)	1993	1.3	-	Proposal
	1993	0.6–0.8	-	Best Available Technology [1]
FCC (B.C.)	1987	6.0		Estimated
	1990	3.0		Assumed
	1993	1.5		Assumed
P&G	1987	6.0	-	Estimated
	1990	3.0	6.0	A.E. license
	1993	1.5	3.0	A.E. license
Daishowa	1990	1.4	2.8	A.E. license
	1993	1.4	2.8	A.E. license

1) Best Available Technology refers to proven and economically acceptable technology for producing fully bleached (90 % brightness) market pulp.

With the AOX levels shown in Table 5-8 the discharge of TCDD for the proposed ALPAC mill would be less than 0.5 μg/ADt (Axegaard et al. 1990). This amount will be diluted with about 50 m^3 effluent / ADt (Table 4-1 and 5-1), thus yielding a concentration of TCDD in the effluent of less than 10 ng per ton of effluent corresponding to less than 10 ppq. This is actually the lowest level being at all detectable with today's analytical techniques (McGrath 1989). Accordingly, with the technology of the ALPAC proposal it is unlikely that any TCDD would be detectable in the effluent. With the best available (and practical) technique as shown in Table 5-8 no TCDD would be detectable in the effluents from the proposed mill.

Figure 5/2 shows the estimated discharges of AOX from the pulp mills along the Peace and Athabasca Rivers for 1987, 1990 and 1993. This period of time is of special interest because substantial expansions are (planned or) taking place along the two rivers as shown by Figure 5/1. Simultaneously, there is an important technological change going on in the mills in order to reduce the environmental impact from bleach plant effluents. The data in Figure 5/2 was obtained by combining data from Table 5–1 and from Table 5–8. For 1993 some different alternatives are shown, as explained by the figure legend.

FIGURE 5/2
Estimated discharges of chlorinated organic compounds (measured as AOX) to the Peace and Athabasca Rivers from pulp mills. Column 1993 a refers to full expansion by Procter & Gamble with 1.5 kg AOX/ADt being discharged and with ALPAC at 1.3 kg AOX/ADt; 1993b refers to full expansion by Procter & Gamble and by ALPAC with best available (and practical) technology discharging 0.7 kg AOX/ADt for all new capacity; 1993c refers to a case with no further expansion (neither by Procter & Gamble nor by ALPAC).

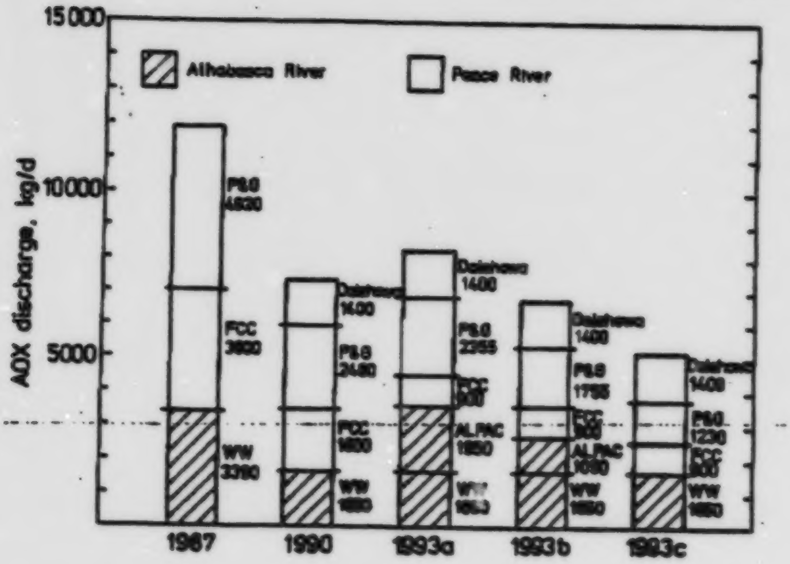


Figure 5/2 shows AOX values only. As explained above under heading "4.3/ Bleaching Technology" the AOX value cannot be regarded as being proportional to the negative impact of the bleach plant effluents. Instead, the negative impact will be reduced much more than AOX. At AOX levels below 1.5–2.0 kg/ADt those substances that are regarded as being the most harmful ones are reduced to insignificant levels, in several cases to levels that cannot be detected using today's analytical techniques.

5.3
Other Pollution Sources

Point source impacts include industrial and municipal discharges. Non-point impacts are those resulting from land use such as agriculture, forestry, and other diffuse loading.

The only municipalities with continuous effluent discharge directly to the Athabasca River are Whitecourt, Edson and Fort McMurray. Hinton's sewage is combined and treated with the Weldwood pulp mill effluents.

Surface mining and extraction of tar sand is the largest industrial activity in addition to pulping industry. There currently exist two mining extraction facilities downstream from Fort McMurray. Only the Suncor Plant has a process discharge to the Athabasca River. Syncrude Plant holds its process effluent in a large tailing pond, but does discharge mine depressurization and runoff water to the Athabasca River via Poplar Creek.

Coal mining activity in the McLeod and Pembina sub-basins have resulted in localized water quality impacts. None of the numerous sawmills and gas processing plants located throughout the basin have a direct effluent discharge to the Athabasca River.

Most existing agricultural activity in the basin occurs south of the mainstem river between the towns of Athabasca and Edson. The Major watersheds included in the agricultural zone are the Pembina and to a lesser extent the LaBiche (Hamilton et al. 1985).

5.4
Sources of Dioxins and Furans

In order to put pulp and paper mills into perspective it would be valuable to have an assessment of all dioxins and furans in Alberta. Since this kind of information is not available, estimates from some other industrialised countries are presented below. Since none of them is directly comparable to the industry and land use in Alberta, some key factors which might be relevant in this province are discussed as well.

Bonsor et al. have presented an assessment on the total dioxin emissions in Ontario in 1986-88 based on an earlier estimate by Ontario Ministry of Environment (MOE) (1985). The incomplete tally was 50 kg/a which consisted of following emission sources:

- 32 kg/a from non-municipal combustion (vehicles, fires)
- 9 kg/a from municipal burning
- 6 kg/a imported from other places (e.g. Niagara dump sites)

- 4 kg/a as contaminants of chlorinated phenols
- 0.11 kg/a from the pulp mills
- trivial amount from herbicides.

The above figures are representing MOE toxicity equivalence units (TEQs).

The total annual releases of dioxin in the United States is estimated to be about 40 kg/a (TAPPI Environmental Conference 1989). Pulp and paper mills accounted 2.8 % of the total amount (Figure 5/3). The unit of the 40 kg/a release was not clearly defined i.e. it may be either 2, 3, 7, 8 dibenzodioxin or some TCDD–equivalent (Eadon or similar).

In Sweden the Nordic TCDD–equivalents have been assessed in 1987 and 1989 (SNV 1990). Some complementary information about industrial and incineration activities are indicated for 1987.

	Industrial Production 1987 (10^6 t/a)	Incineration of Waste 1987 (10^6 t/a)	TCDD–eq– Unit 1987 (g/a)	Emissions 1989 (g/a)
Incinerators		1.6	20	< 20
Burning of hazardous waste		0.03	2–6	2–6
Motor vehicles			5–15	5–15
Iron and steel industries	2.3		15–40	15–40
Non–ferrous smelters and foundries	0.8		5–20	5–20
Iron and steel foundries	0.3		1–10	1–10
Cement and lime kilns	2.5		5–10	5–10
Pulp and paper mills	4.7		19–36	5–6
Coal fired power plants			1	1
Hospital furnaces			10	< 10
Total			83–168	69–138

Hence, in 1989 the total emission from Sweden was estimated to be 0.07–0.14 kg/a, of which pulp and paper mills emitted 4.3–7.2 %.

In order to show a basis for comparison between Ontario, Sweden and Alberta some major factors are presented in Table 5–9.

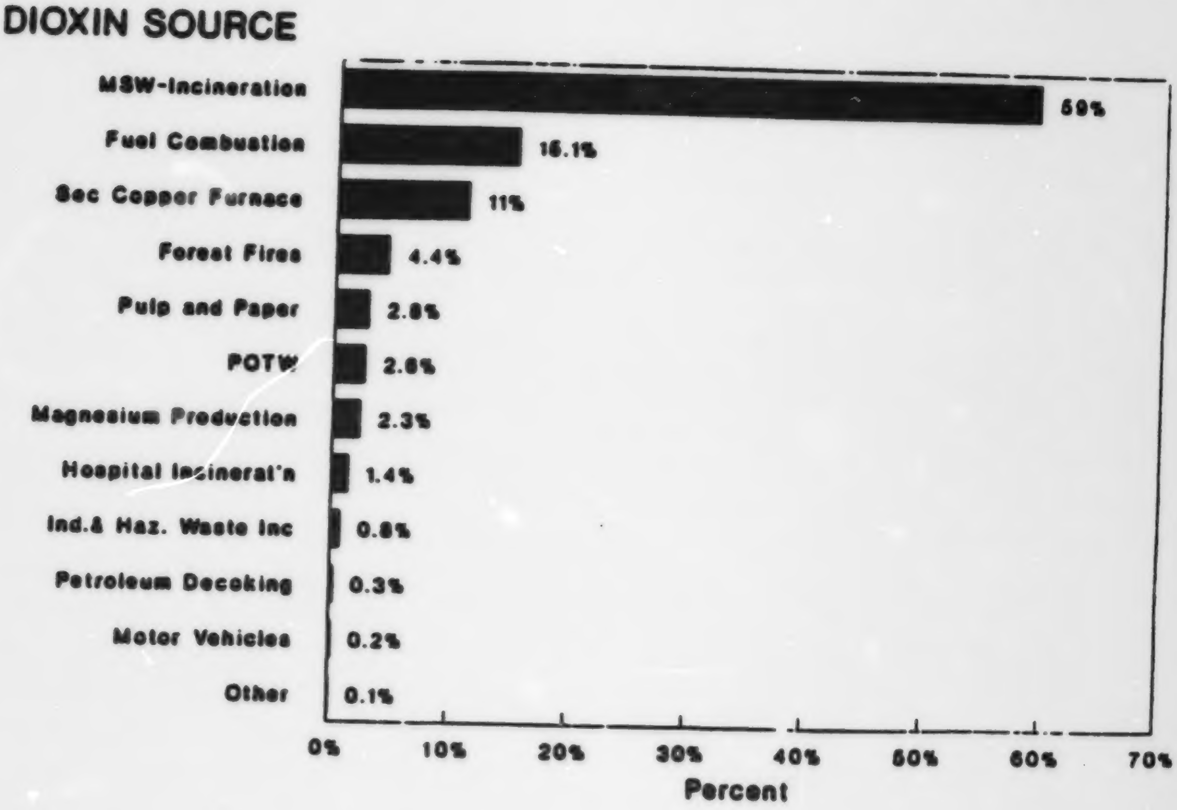
TABLE 5–9
Baseline Data for Dioxin Emissions's Comparison

	Ontario	Sweden	Alberta
Area, km_2	1 070 000	450 000	660 000
Approximate number of inhabitants, million	9.1	8.5	2.4
Bleached kraft pulp production 1987, million tons/a	2.5	4.7	0.5
Estimated dioxin emissions 1987, (kg/a)	50	0.17	?
Dioxins from pulp mills, (kg/a)	0.11	0.04	?

The amount of dioxins/furans being added by human activity to the natural environment constitutes a human health hazard and must be reduced to the lowest levels achievable (Colodey, 1989 – Document G–49). However, it must be remembered that the Canadian Council of Resource and Environment Ministers (1987) and Environment Canada (1985–Document #L–7) estimate that forest fires constitute the greatest source of PCDD and PCDF production in Canada producing some 58 700 g of dioxins/furans per year out of a total annual estimated production of over 175 000 g, and that this is a natural process over which we have effectively no control.

In the Dioxin Conference 1989 in Toronto (Dioxin '89) the role of forest fires was discussed. It is not clear whether or not forest fires have a significant contribution to the 'natural' dioxin formation. In a Canadian research program set up to find out whether dioxin forms in forest fires, air samples were collected above the firing areas in Ontario. In general very low levels of the higher chlorinated dioxins and furans were found (Toshiro et al. 1989).

FIGURE 5/3
U.S. Annual Releases of Dioxin, total releases 40,134 (g/yr)



6
INTRODUCTION TO THE CHEMICAL COMPOSITION OF BLEACHED PLANT EFFLUENTS

6.1
Chlorinated Substances

In a closed bleach plant water system the water is used counter-currently, i.e. clean water is primarily used in the washers of the final stages. In order to achieve an improved wash effect, some clean water is also used in the washer of the first E stage. Because the bleaching stages in a modern five-stage bleach plant are run at alternating high and low pH, the waters are separated into acid and alkaline streams to avoid increased chemicals consumption due to unnecessary neutralisation. The water circulation in the bleach plant may then be according to Figure 6/1.

FIGURE 6/1
The Principle for the Water Circulation in a Five-stage Bleach Plant (Jaakko Pöyry Oy 1987)

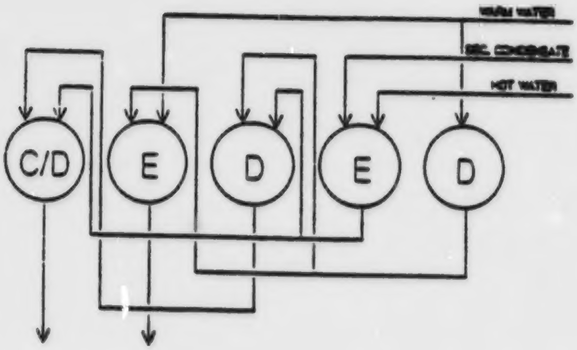


Figure 6-1 shows that the bleach plant effluent is coming both from the acid (DC) and the alkaline (E) stage. The chlorinated organic substances are dissolved in these spent liquor streams.

In the (DC) stage chlorine, chlorine dioxide and lignin react partly through substitution of chlorine into the lignin polymer, and partly through oxidation, causing a breaking of the bonds in the lignin structure. The chlorinated lignin fragments are only partially dissolved in acid conditions, but are extracted from the pulp in the subsequent alkaline E stage. Thus, chlorine-containing organic substances are present in both spent liquors, but in different forms.

Because the dissolved material mainly consists of degradation products of oxidised lignin; along with some chlorinated lignin fragments, extractives and polysaccharides; it is obvious that a large number of different chemical compounds are found in the spent liquors.

Some years back the quantity of chlorinated organic substances was 6–8 kg/ADt, equally distributed in both spent liquors. In these conditions about 30 % of the organically-bound chlorine in the acid liquor was bound in relatively low molar mass substances, whereas the corresponding figure for the alkaline spent liquor is only 5 %. Later determinations at the Finnish Pulp and Paper Research Institute in Helsinki indicate that the mass fraction of chlorine in the high molar mass substance from the alkaline stage decreases from 9.8 % to 2.9 % when the chlorine dioxide substitution is increased from 14 % to 85 %. (However, it should be noted that the higher value is obtained in softwood and the lower value in hardwood bleach liquors.) According to these investigations the dissolved organics in the E stage spent liquor have on average, a substantially higher molar mass than the organics in the (DC) stage effluent (Sågfors et al. 1987).

6.1.1
High Molar Mass Substances

Relatively few studies have been done on the high molar mass substances in the bleach plant spent liquors. Here reference is made to the FPPRI study (Sågfors et al. 1987) in which both the (DC) and the (EO) stage effluents from four different mills were studied. The mills used conventional bleaching sequences. In three mills both softwood and hardwood pulp were produced.

Gel permeation chromatography was used for determination of the molar mass distribution. Only minor differences were noticed when the chromatograms for corresponding liquors from the mills were compared. On the other hand, there was a striking difference between the molar mass distribution when the acid (DC) and the alkaline (EO) waste liquors were compared. In the acid liquor about 20 %, and in the alkaline liquor about 70 % by mass, of the dissolved substances had a molar mass exceeding 1000 g/mole. (This conclusion is drawn presupposing that the UV absorption used for detection is independent of the molar mass of these substances.)

The results indicated that the precursors of the high molar mass substances in the alkaline-spent liquors are hardwood lignin and softwood lignin respectively, and it was found that the absorptivities of the high molar mass substances in the acid stage effluents were low. Acid hydrolysis showed that the high molar mass substances contained up to 30 % of polysaccharides.

This indicated that the high molar mass substances in the effluent from the (DC) stage contained derivatives whose precursors were lignin, hemicellulose and cellulose.

The high molar mass fraction was analyzed for chlorinated phenolics and resin acids. The quantities of the few components found were close to the detection limit, which indicates that the fractionation had been successful and that the high molar mass fraction was not contaminated with compounds of low molar mass.

In addition the high molar mass fraction was examined by infrared (IR) spectrometry both in neutral and acid conditions. The neutral sample had a strong absorbency at bands that indicate carboxylic salts. In the spectra of the acidified samples, these bands were substituted by bands indicating carboxylic acids. A rather strong band indicated conjugated double bonds. Also, indications of aldehydes and ketones were found. No spectral bands indicating the presence of aromatic compounds in the high molar mass substances from the (EO) stage could be detected in softwood bleaching. In the corresponding spectra of the (EO) effluents from two mills bleaching hardwood, there were weak and narrow aromatic bands. At both mills a high degree of chlorine dioxide substitution was used in the chlorination stage. In the high molar mass substances in the spent liquor of the (EO) stage at one mill applying low chlorine dioxide substitution when bleaching hardwood, no aromatic bonds could be detected.

No bands indicating the presence of aromatic compounds could be detected, in the IR spectra recorded of the high molar mass material from the (DC) stage.

Another method used to detect the acute toxicity of the high molar mass substances was the use of water fleas, according to the Finnish standard SFS 6062 and 1 - 2 g/l dilutions (approximately the same dilution as in the original waste liquor). Results showed that the high molar mass substances were not acutely toxic; in fact, a weak toxicity was observed in only a few cases.

With reference to the research report cited (Sågfors et al. 1987), it can be concluded that the high molar mass material in the examined bleach plant waste liquors contains only a small amount of aromatic compounds, and thus most likely consists of branched, partially chlorinated aliphatic carboxylic acids with several conjugated double bonds. The molecules also contain aldehyde and ketone substituents. Therefore, in general, the high molar mass substances are not acutely toxic.

Other research results support these findings. There are, however, different opinions with regards to the molar mass distribution in these substances.

6.1.2
Low Molar Mass Substances

Of the low molar mass substances in the bleach plant effluent, approximately 300 single components were identified; this is estimated to be about 10 % of the total number of these compounds. Only a portion of these are chlorinated. The main proportion of this material consists of methanol, formic and acetic acid and carbohydrates which are degradation products of hemicellulose and cellulose.

Among the chlorinated components, interest has been focused on the following compound groups:

- chloroform
- chlorinated acetic acids
- chlorinated phenolic substances
- chlorinated dibenzo–p–dioxins and dibenzofurans.

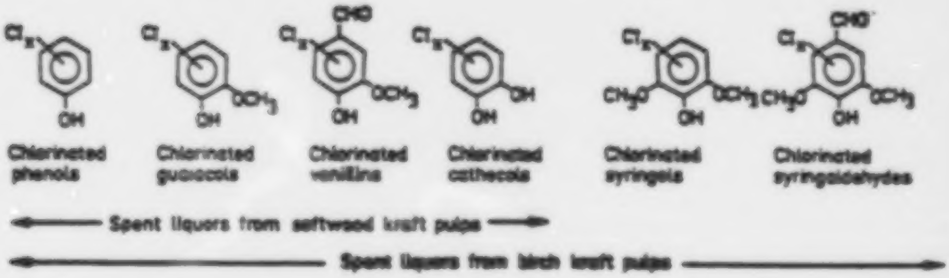
Chloroform is, to a great extent, formed when chlorination occurs in alkaline conditions, i.e., in hypochlorite stages. The formation of up to 0.5 kgs of chloroform per tonne of pulp has been reported (Axegaard 1988). This low molar mass compound is very volatile, and will evaporate from the effluent if the water is aerated. The fate of the chloroform in the atmosphere is largely unknown.

Di– and trichloroacetic acids are formed in fairly large quantities in the bleach plants, (as much as 1 kg per tonne of pulp has been reported). A significant part of the organically bound chlorine is thus contained in these compounds. There are different opinions as to whether the chlorinated acetic acids are environmentally harmful. Apparently, they do not bioaccumulate and they are readily degraded by microorganisms in the recipient water.

The derivatives of catechols and guaiacols have generated special interest among the chlorinated phenolic substances . The structural formulas of these and some other, related compounds are shown in Fig. 6/2.

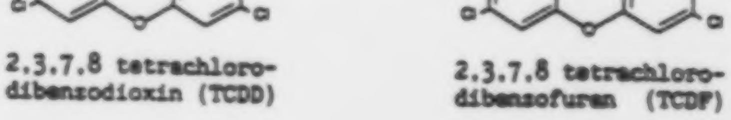
These are typical chlorinated lignin degradation derivatives with the occurrence of 1 – 20 grams per tonne of pulp in the bleach plant effluent. These substances are toxic and show a tendency for bioaccumulation. However, they are quite easily degraded by micro–organisms in biological waste water treatment plants. On the other hand, the microorganisms are able to methylate catechols and guaiachols to anisols and veratrols, which are less toxic but to a greater extent bioaccumulated.

FIGURE 6/2
The Structural Formulas of Some Chlorinated Phenolic Compounds (Kringstad, et al. 1982)


Cl
x
OH
Chlorinated phenols
Chlorinated guaiacols
OCH3
CHO
Chlorinated vanillins
Chlorinated cathecols
CH3O
Chlorinated syringols
Chlorinated syringaldehydes
Spent liquors from softwood kraft pulps
Spent liquors from birch kraft pulps

The category of chlorinated low molar mass components of greatest interest is the group of polychlorinated dibenzo–p–dioxins and dibenzofurans. In tests using animals these compounds have proved extremely toxic. Using modern analytical methods, traces of these compounds have been detected in the pulp mill bleach plants and in sediments in waters close to pulp mills. The structural formulas of the non–chlorinated compounds and the most toxic chlorinated conmers are shown in Fig. 6/3.

FIGURE 6/3
Dibenzo–p–dioxins and Dibenzofurans ("Dioxins")


dibenzo-p-dioxin
dibenzofuran
Cl
2,3,7,8 tetrachloro-dibenzodioxin (TCDD)
2,3,7,8 tetrachloro-dibenzofuran (TCDF)

The polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) may have up to eight hydrogen atoms substituted by chlorine in the structure. The different conmers show a wide range of toxicity depending on the positions of the chlorine atoms. The most toxic is the 2,3,7,8-TCDD, shown in Fig.6/5. The extremely high toxicity is explained by the fact that the molecule fits as the key in a lock in some vital places in the protein chains of living organisms. The toxicity is reduced by an increased number of chlorine atoms in the structure, i.e., by an increased proportion of bound chlorine in the molecule. The toxicity of the dibenzo-p-dioxin with eight chlorine atoms is estimated to one thousand times less than that of 2,3,7,8-TCDD.

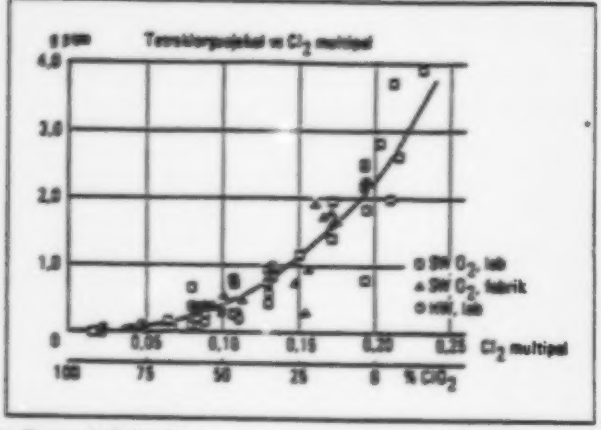
Formation of the PCDDs and the PCDFs results in a series of conmers with various numbers of chlorine atoms in different positions. The concept of TCDD-equivalents has been introduced to extend the concept of tolerable weekly intake of PCDDs and PCDFs to cover the whole range of conmers. The quantity of TCDD having equally high toxicity as the conmers together can be estimated by using a formula.

In certain conditions detectable quantities of these compounds are formed in the pulp bleach plants. The analytical sensitivity is then extremely high, -- 1 picogram per gram, i.e., 1 gram in 1 million tonnes. The quantities that have been detected are of the order of magnitude of 0.000 01 gram TCDD-equivalents per ton of pulp.

The PCDDs and PCDFs have an extremely low solubility in water. Provided these substances are present in the effluent from pulp mill bleach plants, they are most likely adsorbed on suspended solids.

The formation of low molar mass chlorine-containing organic compounds is enhanced by use of molecular chlorine in the first bleaching stage. This would seem logical, since the use of molecular chlorine results in chlorine substituting hydrogen in the molecule, whereas chlorine dioxide has mainly an oxidative effect. Using a high chlorine dioxide substitution in the chlorination stage would then decrease the formation of chlorinated organic substances. This is also the case (as can be seen in Fig. 6/4) with the formation of tetrachloroguaiachol and 2,3,7,8-TCDD versus the applied molecular chlorine multiple at a constant active chlorine multiple.

FIGURE 6/4
The formation of tetrachloroguaiachol and 2,3,7.8-TCDD *versus* the molecular chlorine multiple. The lower axis shows the ClO_2 substitution degree for an active chlorine multiple of 0.18 and kappa number 20 (Axegaard, 1988)

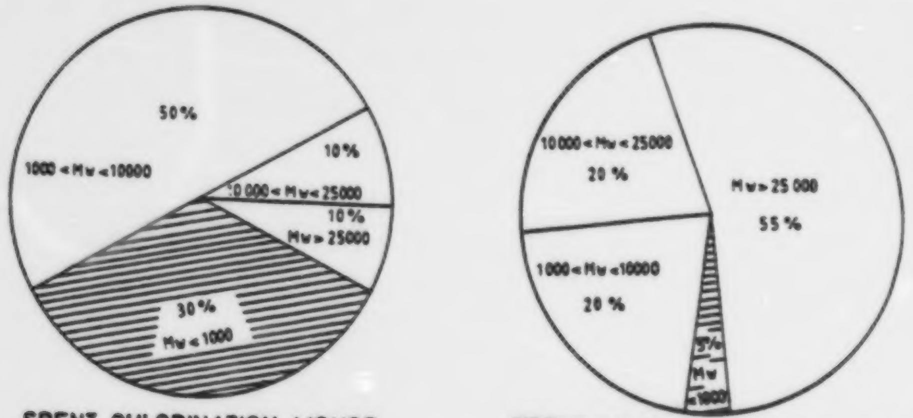


6.1.3
Characterization of Organic Bound Chlorine

Organically bound chlorine is present in a wide range of organic material found in spent bleach liquors. There are many different ways to analyze this particular type of chlorine e.g., AOX and TOCl. Several publications have shown that the ratio between AOX and TOCl varies from 1.0 to 1.7 (Axegaard 1988, Martinsen et al. 1987 and Berthge 1987). The reason for higher AOX concentrations might be due to losses of the high molecular weight matter in the TOCl sorption and elution steps or losses of volatile compounds in the solvent concentration steps (Martinsen et al. 1987). The majority of publications have described TOCl and its composition, because AOX analysis is a relatively new method for determing organically bound chlorine. However, characterization of TOCl gives an idea of the composition of organically bound chlorine compounds in spent bleach liquors.

Many investigations have shown that in chlorination liquor, about 70 % of the organically bound chlorine is present as high-relative-molecular-mass material ($M_r>1000$) when ultrafiltration is used for dividing the spent bleach liquors into fractions of different relative molecular mass, whereas about 95 % of the organically bound chlorine belongs to this class in alkali extraction liquor (Lindström et al. 1981). Correspondingly, about 30 % of the organically bound chlorine in spent chlorination liquor, and approximately 5 % in alkali extraction liquor, is of low-relative-molecular-mass ($M_r<1000$) material (Figure 6/5). The percentages differ from these values to some extent if kraft pulp is prebleached with oxygen, or chlorine is partially replaced with chlorine dioxide during the first bleaching stage (Anon 1982, Kringstad et al. 1984).

FIGURE 6/5
Distribution of the Organically Bound Chlorine by Mass in Substances of different Molar Mass in the Acid and Alkaline Spent Liquor (Kringstad and Lindström, 1982)



SPENT CHLORINATION LIQUOR

SPENT CAUSTIC EXTRACTION LIQUOR

The structure of high-relative-molecular-mass material of spent bleach liquors, so-called "chlorolignin", is poorly defined at present. It is known that it has high chlorine-to-carbon ratio. The content of aromatic nuclei is surprisingly low and a major part of the material consists of crosss-linked, probably unsaturated aliphatic compounds, which include acidic groups (Lindström & Österberg 1984; and Österberg & Lindström 1985).

The low-molecular-mass materials can be divided into three main groups: acidic, phenolic, and neutral compounds. The amounts of these compounds vary between wood species; the bleaching conditions; and the degree of delignification and washing of unbleached pulp. Ether-soluble low-relative-molecular-mass (M_r<1000) OCl consists of about 70 % chlorinated carboxylic acid, 25 % chlorinated phenolic and 5 % chlorinated neutral compounds in the bleaching liquors (Anon 1982). Oxygen prebleaching will generate smaller quantities of all of these compounds and, for example, chloroform is found only in very small quantities in such liquors. The use of chlorine dioxide for partial replacement of chlorine in the bleaching process, increases the formation of chlorinated phenols with respect to the increasing degree of replacement (Voss et al. 1980). The amount of chlorinated phenols reaches a maximum at 50 % of chlorine dioxide substitution. If more than 50 % is substituted the quantity of chlorinated phenols starts to decline.

A rough estimate has been made of the total content of organically bound chlorine in compounds identified in spent bleach liquor. Indications are that this chlorine will account for about 10 % in spent chlorination, and 35 % in alkali extraction liquor, of the total content of organically bound chlorine present in low-relative-molecular-mass (M_r<1000) materials (Kringstad et al. 1984). These estimates suggest that a considerable number of individual low-relative-molecular-mass compounds have yet to be identified in both types of liquor.

Biological treatment of bleached kraft total mill effluents reduces the discharge chlorinated organic compounds . However, there is much less information available concerning the presence of these compounds in biologically treated effluents than there is concerning the presence of such compounds in the individual spent bleach liquors. Still, it is known that effectively operating activated sludge treatment reduces the amount of AOX to about one half of the amount that would normally be discharged from the bleach plant (see Figure 4/9). The reduction of chlorinated phenolics is even more efficient. Fairly low amounts of chlorinated phenolics and chloroform, and only traces of chloroacetones, can be detected in the effluents after activated sludge treatment (Gergov et al. 1988).

6.2
Summary of Analytical Chemistry of Dioxins and Dibenzofurans

Some general remarks on the method used trace analysis are made. The results of different laboratories used in the ALPAC Environmental Impact Assessment Review have been evaluated according to the methods published elsewhere.

In principle, the analysis of polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) is possible with a high resolution gas chromatography (GC) equipped with an electron capture detector; however, in practice such analyses are usually made by mass spectrometric detection. Mass spectrometric (ms) analysis is useful when the number of isomers is large (75 dioxin and 135 dibenzofuran congener), concentrations are low, and the very high sensitivity and specificity is needed. This may be achieved either by low resolution or high resolution mass spectrometry. High resolution gas chromatography/mass spectrometry is the most sensitive instrumentation for the analysis of polychlorinated dioxins and furans. Tandem mass spectrometers (GC/MS/MS) have the highest selectivity, but usually the sensitivity is lower than in the high resolution GC/MS.

Quantification of PCDDs and PCDFs is based on peak areas and response factors of labelled isomers. In the most sensitive method the monitoring of tetra- octachlorinated congeners in five groups is used. At least one internal standard for dioxins and one for furans should be present in each group. In addition, recovery and injection standards should be used. The resolution of the spectrometer is a very important factor in evaluating the selectivity and sensitivity of the analysis method. Sampling, packaging, storage, preparation, extraction and clean-up of the sample all affect the reliability of the results. Unfortunately this kind of information was not available for this study. Therefore, it is not possible to carefully review the analytical methods used in different laboratories.

In many cases, results of dioxin analyses are compared to toxicity equivalence of samples. The calculation of TCDD equivalence of the sample is based on the toxicity equivalence factors determined for most toxic 2,3,7,8-substituted congeners. Unfortunately, different toxicity equivalence factors (TEQ) are used in different laboratories, resulting in large variations in the results of the same original data. When comparing results obtained from different laboratories, the results should be calculated using the same toxicity equivalence factors. In Nordic countries the Nordic Proposal (Ahlberg 1989) is often used. In this proposal the factors of the toxic congeners are almost equivalent to international TEQ numbers. It is recommended that all dioxin results in this Environmental Impact Assessment Review should be calculated according to some international toxicity equivalence factors before any comparison of dioxin data of each sampling is made.

Laboratories that have the ability to analyze polychlorinated dioxins and dibenzofurans should follow strict Quality Assurance/Quality Control (QA/QC) procedures. Recoveries obtained for each standard should be reported and should typically be in the range of 40 to 120 %. At least one blank sample is generally included for each set of samples. At least one of the samples in each set is usually analyzed in duplicate, and the results of these analyses are included in the report.

Some of the laboratories cited in the report of the ALPAC Environmental Impact Assessment Review Board seem to have acceptable QA/QC procedures. However, in many cases QA/QC information was not available. Thus, such data should be considered as preliminary data, not as scientific facts.

The reported concentrations of PCDD's and PCDF's are extremely low – in many cases lower than a detection limit (1 – 2 ppt in solid matter and 0.03 – 0.05 ppt in effluents). It is quite surprising that only the concentrations of two congeners, namely 2,3,7,8-tetrachlorodibenzo-p-dioxin and 2,3,7,8-tetrachlorodibenzofuran, are reported. It is true that 2,3,7,8-TCDD is the most toxic congener, but in many samples there are a lot of other tetra- through octachlorinated congeners whose concentrations may be much higher than the concentrations of the two congeners noted above. It is almost impossible to judge the origin of polychlorinated dioxins and dibenzofurans, if the profile of the congeners has not been determined. In some cases 2,3,7,8–tetrachlorinated dioxins and furans are derived from the chlorine bleaching of pulp, but other sources produce these congeners as well. The profile of chlorinated dioxins from bleach plants is completely different from the profile originating from other sources, for instance, incineration, fires of fossil fuel and waste, or forest fire.

In conclusion, the amount of information reported with the dioxin analytic data is inadequate for a comprehensive and accurate.review of the methods used in different laboratories. Additional dioxin analyses in laboratories which have detailed QA/QC protocol is highly recommended. Special attention should be paid to sampling sites, and to sampling and storage of the samples prior to analysis.

7
FUTURE ENVIRONMENTAL IMPACTS

7.1
River Dynamics and Water Quality

7.1.1
River Hydraulics

There are extensive, and for the most part, quite recent data available on the hydrology of the Athabasca River (e.g. Alberta Environment 1989a, Hamilton et al. 1985, Bothe and Siemonsen 1989, Trevor et al. 1988, Thompson and Fitch 1989, ALPAC 1989a). These provide adequate baseline information on the physical framework of the Athabasca River ecosystem, and allow for calculations and assessments to be made regarding the environmental impacts of the planned forest industry development.

The Athabasca River stems from the Columbia Icefields in the Rocky Mountains. The total area of the river basin is 157,000 sq.km, about one-half of which is upstream of the Town of Athabasca (Hamilton et al. 1985). The total length of the Athabasca River is 1464 km and the total elevational drop is 1254 m. The longitudinal profile of the river is characterized by varying channel slopes (Figure 7/1). The slope reaches its maximum elevation in the Rockies, upstream from Jasper, and its minimum lowest points is located in the lowest reach downstream of Fort McMurray. The width of the river is about 60 m at Jasper and widens to 450 m at Fort McMurray (Hamilton et al. 1985).

The Athabasca River runs from the Rocky Mountains to Lake Athabasca, where it joins with the Peace River to form the Slave River, which in turn runs into Great Slave Lake. Waters of the Great Slave Lake flow through Mackenzie River to the Beaufort Sea in the north (Figure 7/2). About 25 % of the water at the mouth of the Mackenzie River comes from the Peace and Athabasca Rivers.

The Peace River has its headwaters in the Rocky Mountain Trench. Its length is about 1600 km and the delta it forms with the Slave River creates complex water flow patterns. The Peace River accounts for 60 % of the Slave River flow at the confluence. The remaining 40 % of the flow consists of drainage from Lake Athabasca (15 %) and the Athabasca River flow (25 %) (Alberta Environment 1989a). During the early summer, waters from Lake Athabasca and the Athabasca River flow into the delta causing it to flood.

Figure 7/1
LONGITUDINAL PROFILE OF THE ATHABASCA RIVER

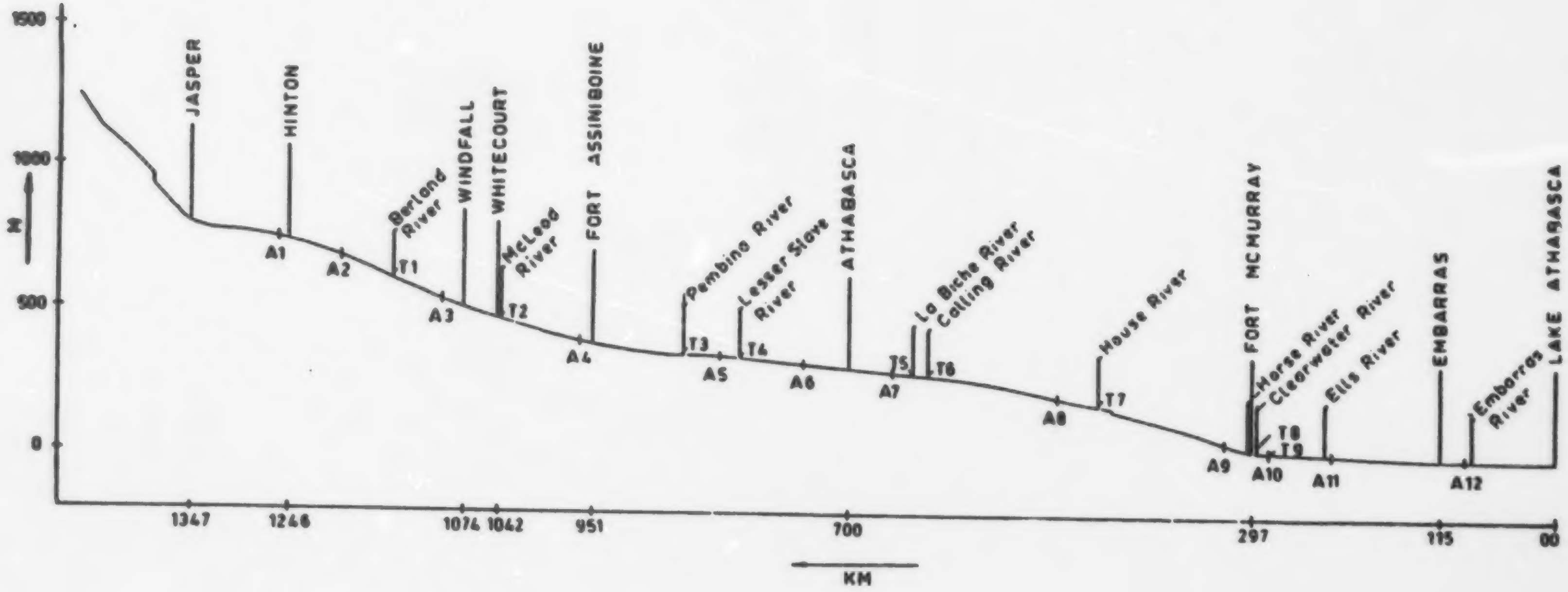
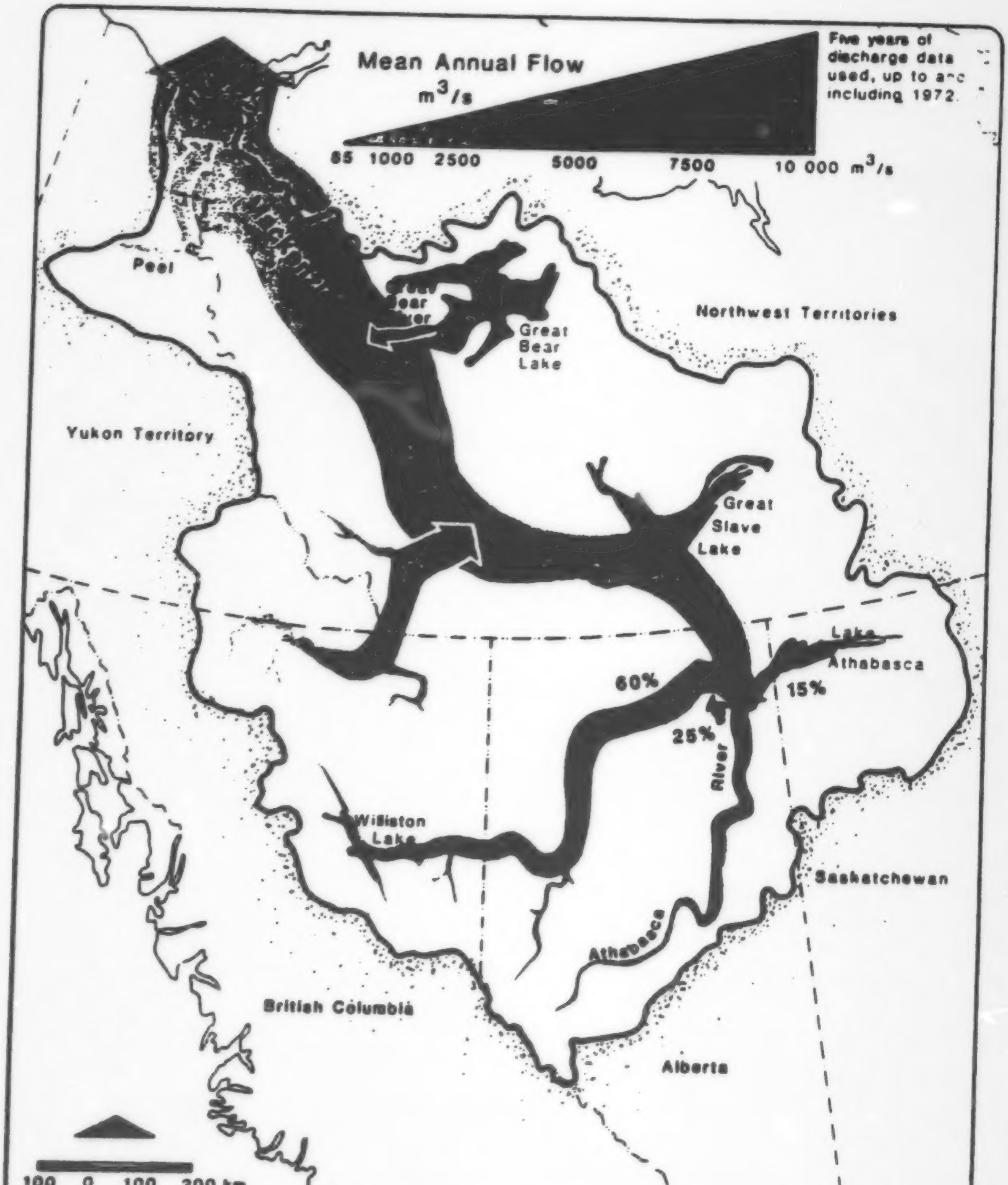


Figure 7/2


Mean Annual Flow
m³/s
65 1000 2500 5000 7500 10 000 m³/s
Five years of discharge data used, up to and including 1972.
Peel
Great Bear River
Great Bear Lake
Northwest Territories
Yukon Territory
Great Slave Lake
Lake Athabasca
60%
15%
25%
River
Williston Lake
Athabasca
Saskatchewan
British Columbia
Alberta
100 0 100 200 km

Mackenzie River System

The proposed site for the ALPAC kraft pulp mill is between the Town of Athabasca and the Calling River confluence. The most immediate impacts of the ALPAC mill effluents will be located in the river reach between the mill site and the Grand Rapids. This reach is about 200 km long and has a moderately high slope (see Figure 7/3). During the low period (flow about 100 m^3/s at Athabasca) the mean depth of the Athabasca River between Hinton and the Town of Athabasca is from 1 m to 2 m, and the velocity is approximately 0.5 m/s (Trevor et al. 1988). Detailed hydraulic geometry data of the reach downstream from Athabasca and upstream of the Grand Rapids is not available. Thompson and Fitch (1989) give measured data on open-water, near mean flow conditions (Table 7-1).

TABLE 7-1
Reach-average Hydraulic Parameters Measured
Downstream from the Town of Athabasca

Reach (km)	Discharge (m^3/s)	Velocity (m/s)	Mean depth (m)
0 - 100	436	0.81	1.95
100 - 400	501	1.03	1.83

The hydraulic parameters are least accurate under ice-covered conditions, and the travel time estimate for the reach from Athabasca to Fort MacMurray is probably accurate to only ± 25 % (Thompson and Fitch 1989).

The climate in the Athabasca River basin area is continental. The mean January temperature ranges from −15 to −25 °C; the average in July is around 15 °C and only occasionally exceeds 30 °C (Hamilton et al, 1985). Two-thirds of the annual precipitation (400–800 mm) occurs in the summer months and the annual snowfall in most of the basin is approximately 140 cm. The river has the ice cover from mid-November to early April at Athabasca (Alberta Environment 1989a).

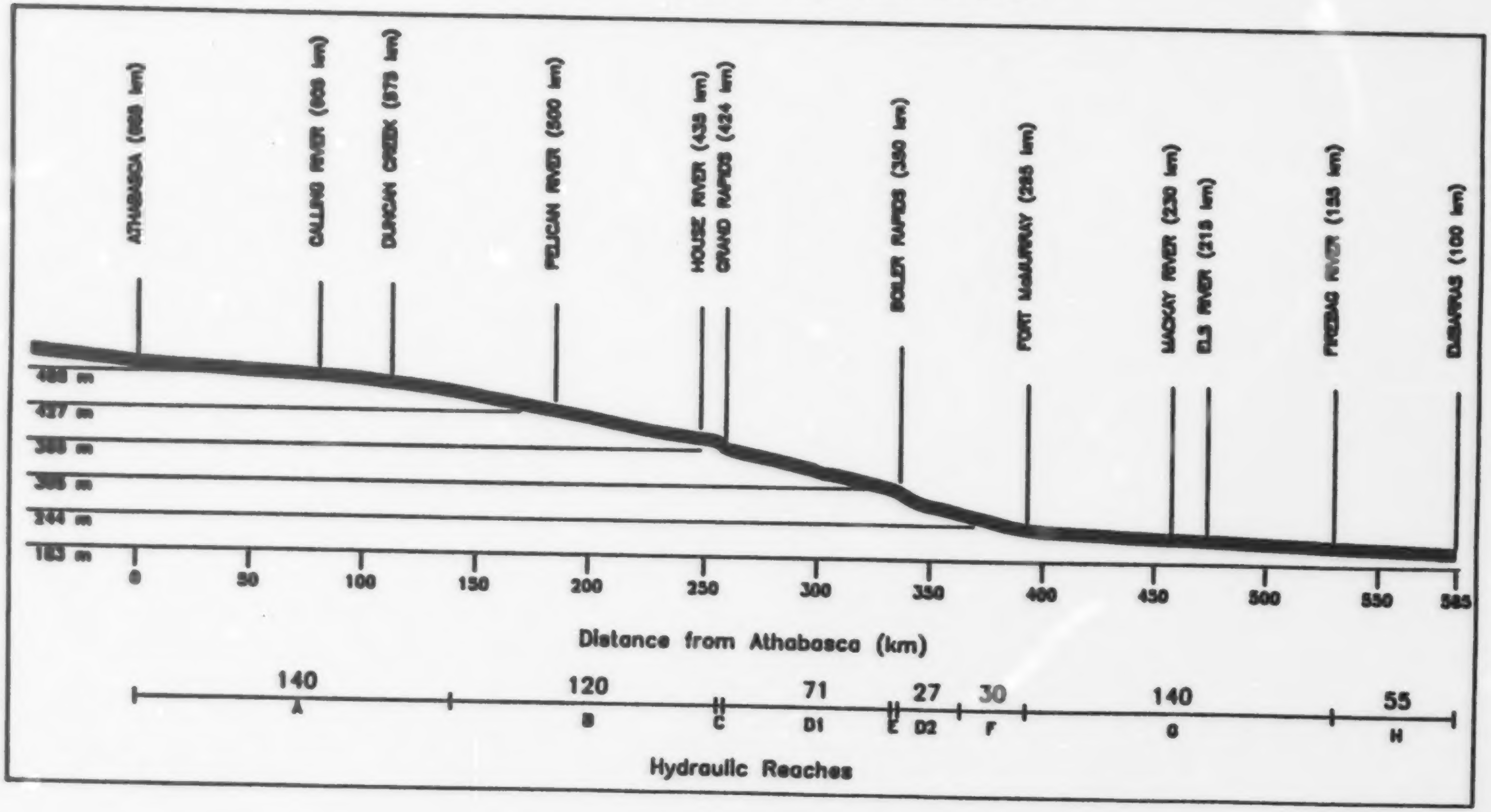
The seasonal flow of the Athabasca River varies widely. Flows are highest in early summer (June–July) and lowest in winter (January–March) Figure 7/4). In the tributaries the high and low flows occur earlier, in May and in January–February respectively (Noton and Shaw 1989). Historical monthly stream flow and temperature data at Athabasca are given in Table 7-2.

FIGURE 7/3

Athabasca River Profile

Athabasca to Embarras

Reaches of Like Leopold – Maddock Relationships



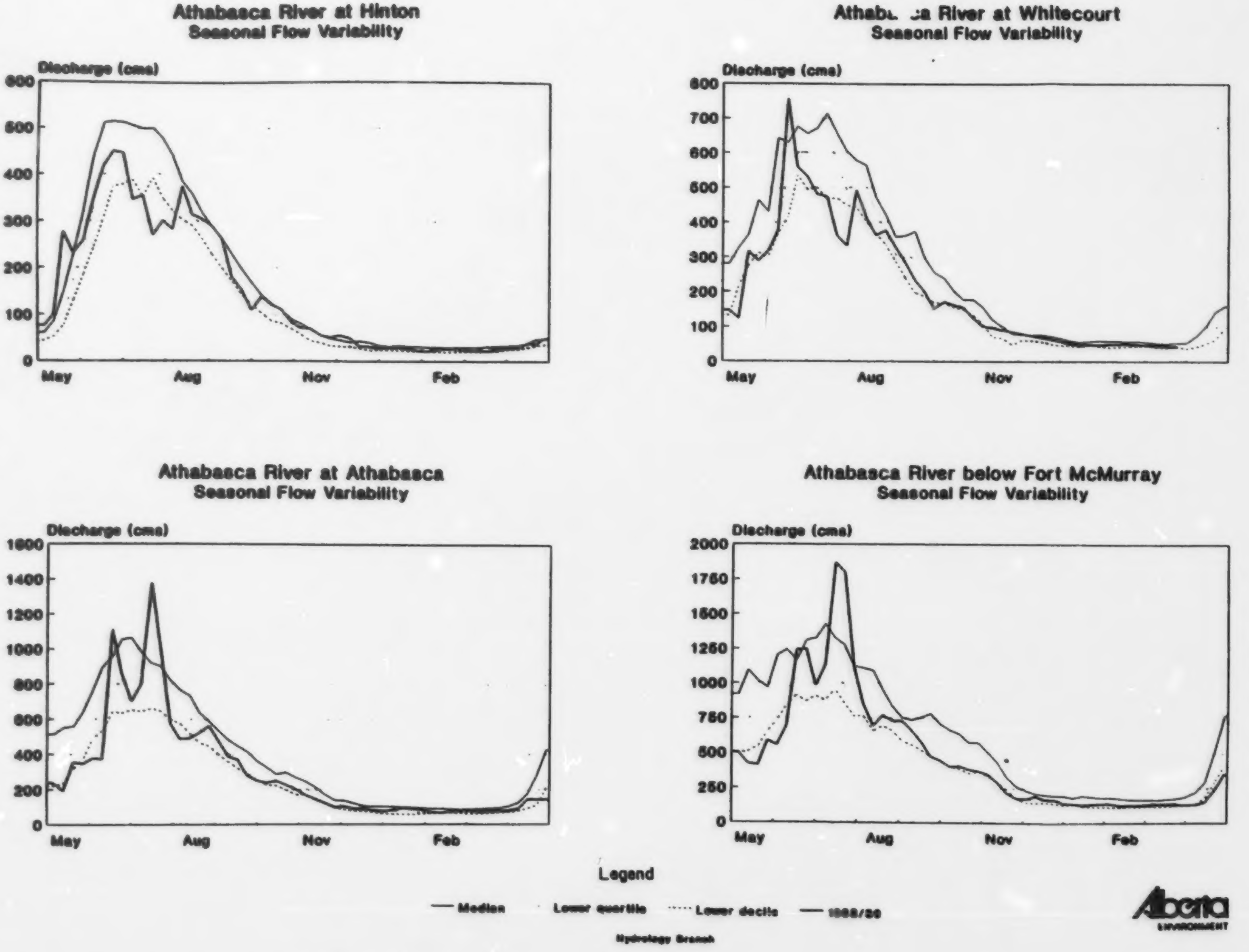


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FIGURE 7/4
Seasonal Flow Variability at Selected Sites in the Athabasca River

TABLE 7-2
Monthly Historical Average Discharge (m^3/s) and Temperature (°C) of Athabasca River at Athabasca (from ALPAC 1989a)

Month	Condition	Temperature (°C)	Discharge (m^3/s)
January	ice cover	0.4	96
February	ice cover	0.5	90
March	ice cover	0.5	96
April	break-up	2.1	324
May	open water	9.4	688
June	open water	14.5	1,030
July	open water	17.0	995
August	open water	16.7	683
September	open water	12.1	487
October	open water	7.2	315
November	freeze-up	1.1	186
December	ice cover	0.6	119

The most critical flow condition in terms of pulp mill effluent impact on the aquatic environment of the Athabasca River occurs during ice-covered winter period when the temperature is lowest, reaeration is at a minimum, and dilution conditions are most unfavourable.

The term 7Q10 flow designation is used for the flow having one in ten year return period and a duration of 7 days to represent the low flow of the river. Bothe and Siemonsen (1989) have calculated these 7Q10 values for Hinton, Whitecourt, Athabasca and Fort MacMurray centered flows as total flow and local tributary contributions to it (Table 7-3). At Athabasca the 7Q10 value is 53 m^3/s.

Calculated travel time during 7Q10 flow from Athabasca to Fort MacMurray is approximately 12 DAYS, (Table 7-4).

TABLE 7-3
Athabasca River Basin Annual 7Q10 Flows (m^3/s)

	Point of Interest							
	Hinton		Whitecourt		Athabasca		Fort McMurray	
	Local	Total	Local	Total	Local	Total	Local	Total
Athabasca at Hinton		15.8		25.1		27.1		31.4
Hinton to Berland Local	5.2	21.0	0.7	25.8	2.3	29.4	2.4	33.8
Berland River	12.0	33.0	1.7	27.5	5.2	34.6	5.6	39.4
Sakwatamau River	2.9	35.9	0.4	27.9	1.3	35.9	1.4	40.8
Berland to Windfall Local	11.3	47.2	1.6	29.5	5.0	40.9	5.3	46.1
Athabasca near Windfall		47.2		29.5		40.9		46.1
McLeod at Whitecourt	5.0	52.2	3.8	33.3	2.3	43.2	8.2	54.3
Athabasca at Whitecourt		52.2		33.3		43.2		54.3
McLeod to Freeman Local	0.4	52.6	1.4	34.7	0.1	43.3	0.1	54.4
Freeman River	0.4	53.0	1.2	35.9	0.1	43.4	0.1	54.5
Freeman to Pembina Local	0.7	53.7	2.3	38.2	0.2	43.6	0.2	54.7
Pembina River	3.1	56.8	5.5	43.7	1.8	45.4	2.0	56.7
Pembina to Lesser Slave Local	1.6	58.4	5.0	48.7	0.3	45.7	0.5	57.2
Lesser Slave River	15.6	74.0	31.3	80.0	7.5	53.2	8.9	66.1
Lesser Slave to Athabasca Local	0.6	74.6	2.0	82.0	0.1	53.3	0.2	66.3
Athabasca at Athabasca		74.6		82.0		53.3		66.3
Athabasca to House Local	19.3	93.9	34.1	116.1	7.5	60.8	5.0	71.3
House River	0.8	94.7	1.4	117.5	0.3	61.1	0.2	71.5
House to Fort McMurray Local	7.5	102.2	13.2	130.7	2.9	64.0	1.9	73.4
Clearwater River	61.0	163.2	76.5	207.2	44.9	108.9	40.6	114.0
Athabasca below McMurray		163.2		207.2		108.9		114.0
Athabasca below McMurray to Poplar Local	0.1	163.3	0.1	207.3	0.1	109.0	0.1	114.1
Poplar Creek	0.0	163.3	0.0	207.3	0.1	109.1	0.1	114.2
Poplar to Steepbank Local	0.1	163.4	0.1	207.4	0.1	109.2	0.1	114.3
Steepbank River	0.4	163.8	0.4	207.8	0.5	109.7	0.5	114.8
Steepbank to Muskeg Local	0.2	164.0	0.2	208.0	0.3	110.0	0.3	115.1
Muskeg River	0.3	164.3	0.3	208.3	0.4	110.4	0.4	115.5
Muskeg to MacKay Local	0.0	164.3	0.0	208.3	0.0	110.4	0.0	115.5
MacKay River	0.5	164.8	0.5	208.8	0.5	110.9	0.4	115.9
MacKay to Ells Local	0.0	164.8	0.0	208.8	0.1	111.0	0.0	115.9
Ells River	1.0	165.8	1.0	209.8	1.5	112.5	1.4	117.3
Ells to Firebag Local	0.7	166.5	0.7	210.5	1.0	113.5	0.9	118.2
Firebag River	9.1	175.6	9.1	219.6	6.6	120.1	6.2	124.4
Firebag to Embarras Airport Local	0.5	176.1	0.5	220.1	0.7	120.8	0.7	125.1
Athabasca at Embarras Airport		176.1		220.1		120.8		125.1

TABLE 7-4
Travel Time Estimates for Ice-cover Conditions With Concurrent 7Q10 Flows at all Stations Along the Athabasca River (from ISL and Dominion, 1989)

Hinton to Whitecourt - approximately 4.8 days

Whitecourt to Lesser Slave River - approximately 10.4 days

Lesser Slave to Athabasca - approximately 4 days

Athabasca to Fort McMurray - approximately 12 days

Fort McMurray to Embarras - approximately 6 days

7.1.2
Present Water Quality

Water quality for the Athabasca River has been surveyed and reviewed in several report during the 1980s. The present water quality is affected by the following: natural and non-point anthropogenic runoffs; effluent discharges from Weldwood bleached kraft pulp mill before expansion in 1990 (in operation since 1956), and Millar-Western CTMP mill (in operation since 1989); the discharges from the tar sands plants; and municipal waste water discharges. The reports listed below have been used as the sources of baseline data.

1. Water Quality Overview of Athabasca River Basin (Hamilton et al. 1985)
   - historical water quality since 1970, three sampling sites (Jasper, Town of Athabasca, Fort McMurray)
   - six basin-wide synoptic sampling surveys during 1984 and early 1985, (twelve main stem sites and nine tributary sites)
2. Winter Water Quality in the Athabasca River System 1988 and 1989 (Noton and Shaw 1989)
   - five surveys from January to March in 1988 and 1989 (up to 35 main stem, 29 tributary and 7 effluent sites)
3. An Assessment of the Effects of the Combined Pulp Mill and Municipal Effluents at Hinton on the Water Quality and Zoobenthos of the Athabasca River (Anderson 1989)
   - two water quality surveys in fall 1985 and winter 1986 (sites from upstream of Hinton to 60 km downstream of effluent outfall)

The surveys by Hamilton et al. 1985 and Anderson 1989 were made when only the Weldwood kraft pulp mill at Hinton was operating. The Noton and Shaw 1989 data also includes the effect of the Millar-Western CTMP-mill effluent on river water quality.

The Athabasca River can be divided into three distinct natural water quality zones and three distinct water quality seasons (Hamilton et al. 1985). The most upstream zone from Jasper National Park to Fort Assiniboine is characterized by fast flow; good water quality; high alkalinity and hardness of water; and low concentrations of suspended solids, organic carbon, and nutrients. Bottom deposits are scarce and epilithic algae are the dominant primary producers.

The intermediate reach from Fort Assiniboine to Fort McMurray is a transition zone, where alkalinity and hardness decrease and other constituents increase, mostly due to tributary loadings. Upstream of Fort McMurray the river gradient is rather steep and the channel is narrow causing scouring of the river bed and bank erosion, which increases the loading of particulate material.

In the downstream reach from Fort McMurray to Lake Athabasca the concentrations of suspended solids and associated parameters such as organic carbon, particulate nutrients and metals are at a high level for most of the year. This loading is mainly derived from upstream tributaries and channel resuspension. Indications exist that the larger particles are deposited in the lower reach, but smaller particles tend to be transported to Lake Athabasca. Primary production is dominated by phytoplankton.

The yearly water quality seasons consist of the ice covered season, the season from break-up to the end of July (water quality controlled by snowmelt runoff) and the season from the beginning of August to freeze-up (characterized by summer rainstorms and maximal instream biological activity).

Analysis of the water quality data has led to the conclusion that in almost all instances, tributary streams account for 90 % or more of all measured constituent loadings. Effluents from municipal and industrial plants (e.g., tar sands processing) have only local effects on river water quality.

It is also noticed that many Alberta Surface Water Quality Objectives (ASWQO) (total phosphorus, iron, manganese, phenol, copper, zinc, total nitrogen, aluminum, arsenic and mercury) and certain objectives for aquatic life and wildlife are regularly exceeded; but however, this is mostly due to regional variations in natural water quality (Hamilton et al. 1985).

Increased levels of the following constituents in river water have been traced to effluents of operating pulp mills in the Athabasca River (Hamilton et al. 1985, Anderson 1989, Noton and Shaw 1989):

dissolved organic carbon
suspended solids
tannin and lignin
colour
phenols
odour
trace organics
manganese
zinc
phosphorus
nitrogen
sodium
chloride
sulphate
sulphate

Most metals were not affected by the effluents (Noton and Shaw 1989). The pulp mill effluents do, however, contribute to a decrease in the concentration of dissolved oxygen during the winter months.

The concentrations of constituents such as suspended solids, particulate carbon, particulate nitrogen, and total phosphorus declined rapidly downstream, and are often near background level beyond 60 km of the effluent outfall. The rapid decline in concentrations is likely due to degradation, settling out and dilution (Anderson 1989). During low flow conditions the elevated concentrations of measured water quality parameters persist for a distance of 50 to 75 km from the site of the effluent outfall. During the high flow period no significant alteration in natural water quality was observed (Hamilton et al. 1985).

No measured data exist of the total amount of chlorinated organic compounds or chlorinated dioxins and furans in the river water. Some chlorinated and non–chlorinated trace organics have been detected at low part of billion levels in the Athabasca River, and likely originated from pulp mill effluents (Noton and Shaw 1989).

When evaluating possible effects on the Slave River the water quality of both the Peace River System and the Athabasca River are of concern. Four pulp mills are currently operating in the Peace River Basin. The baseline survey of water quality in the Peace River concludes that for the constituents and sites investigated there were no adverse effects from the existing mills on the water quality in the main stem of the Peace River. These results attest to the high effluent dilution capacity of the river and/or the assimilative capacity of intervening water bodies. The transport and distribution of chlorinated organic compounds have not been examined for either the Athabasca or the Peace Rivers (Noton 1989).

7.1.3
Future Water Quality Assessments

Typical constituents in pulp mill effluents that affect the receiving water quality are the dissolved and suspended organic compounds, suspended solids, phosphorus and nitrogen. Bleached kraft mill effluent is unique in that it contains chlorinated organic compounds. However, concentrations of metals and inorganic ions are low enough that they are not likely to have harmful effects on the river water.

The biodegradation of dissolved organic compounds consumes dissolved oxygen from the water, increases turbidity and promotes the growth of saprophytic, "slime forming", organisms. The high molecular weight fraction of dissolved organics consists mostly of lignin-related compounds, which are high in color and fairly stable. They decrease light penetration in water affecting primary production; increase long-term oxygen consumption; and are an aesthetic problem as well.

Discharge of suspended solids increase the turbidity of water and have a secondary affect as being an "absorbent" and a carrier of trace compounds with low water solubility.

Phosphorus and nitrogen are the essential nutrients for plants and elevated concentrations of these nutrients in water may cause excessive algal growth.

Trace organics contain various wood extractives and reaction products of the pulping and bleaching process. Some of these substances are known to be ecologically harmful. Chlorinated organic compounds are a variable group of low and high molecular weight compounds, only a part of which have been identified. Some of the identified low molecular weight compounds are moderately or highly toxic or mutagenic. The total amount of chlorinated organics is usually measured as AOX.

The additional impact of the effluent from the proposed ALPAC pulp mill on the water quality of the Athabasca River must be evaluated against the "background" water quality, with consideration given to other effluent discharges to the river. The effluent discharge levels from the ALPAC mill were assessed in Chapter 5, in accordance with the best available technology and those values are used in the river water quality evaluation. The present as well as the future effluent discharges from the four operating and future pulp mills are taken into account.

Tables 7-5 and 7-6 show the discharges and expected pulp mill effluent loadings by the Athabasca River that are used in the water quality evaluations.

Water quality in the Athabasca River is an important control on the water quality at downstream reservoirs, such as Lake Athabasca and Slave River. However, Slave River water quality is mostly controlled by water discharged from the Peace River System, which accounts for approximately 60 % of the flow (whereas the Athabasca River Accounts for 25 % of the flow) (see Figure 7/13).

TABLE 7-5
Annual and Winter (January, February and March) Mean Discharges for the Period of Record and the Annual 7Q10 Flows in the Athabasca River

Athabasca River	Major tributaries*	Annual (m^3/s)**	Winter (m^3/s)**	7Q10 $(m^3)/s$***	% at Embarras*
Hinton		171	33	16	
	Berland R.				5.6
	McLeod R.				6.7
	Pembina R.				4.6
	Lesser Slave R.				6.4
Athabasca		431	94	53	
	La Biche R.				6.7
	Clearwater R.				18.5
Fort McMurray		664	174	114	
Embarras		783	208	-	
					48.5

---

* from Hamilton et al. 1985
** from Water Survey of Canada, Environment Canada
*** from Noton et al. 1989

% at Embarras = average annual contribution that tributary as a (%) of the discharge at Embarras

TABLE 7-6
Estimated Pulp Mill Effluent Discharges into the Athabasca River in 1993 Used in Water Quality Estimates (from Alberta Environment 1990b and ALPAC 1989a

	Production ADt/d	BOD5 kg/ADt	TSS kg/ADt	AOX kg/ADt	TOT.P* g/ADt
Weldwood	1100	3.0	NE	1.5	55
Millar Western	680	3.0	5.0	NA	88
Alberta Newsprint Co.	700	3.0	5.0	NA	57
Alberta Energy Co.	350	3.0	5.0	NA	91
ALPAC** (proposed)	1500	1.5	3.0	1.3#	60
				0.6 (BAT)	

NA = not applicable
NE = not established
* = expected load (Alberta Environment 1989)
** = proposed and estimated values
BAT = best available technology
# = corresponding to 1 kg TOCl/ADt

7.1.4
Dissolved Oxygen

When the Athabasca River is not covered by ice the high reaeration rate is sufficient to keep dissolved oxygen in the water at well above critical values in all the development scenarios presented for the forest industry along the river. Low flow and almost complete ice cover prevents reaeration during winter for most of the Athabasca River. This makes it very vulnerable to oxygen depletion due to organic load discharges during late winter.

Substantial effort has been placed on developing and calibrating a water quality model which would enable differentiation and forecasts of certain water quality constituents (Hamilton et al. 1988, Thompson and Fitch 1989, Macdonald et al. 1989, Macdonald and Hamilton 1989). The developed model DOSTOC is applied to calculate impacts of several waste water discharges on dissolved oxygen (DO) in the Athabasca River mainstem and in the Lesser Slave River (Macdonald and Hamilton 1989, ALPAC 1989b).

The basic equation of DOSTOC is that proposed by Streeter and Phelps (1925). DOSTOC has a stochastic calculation option which is not applied to the Athabasca River. In the case of using theoretical, basically statistical 7Q10 flow the exclusion of this option is well justified. DOSTOC is a steady-state, one-dimensional (travel) model including several DO-related components (HydroQual and Gore & Storrie 1989). The model includes a few simplifying assumptions, but they do not make it invalid in this application.

The hydrological data base of the DOSTOC application to the Athabasca River is extensive and DO/BOD data collected during winter 1989 surveys is sufficient to calibrate the model in near-7Q10 flow conditions. Because calibration is of primary importance in developing a sound model application, the basic report of Macdonald and Hamilton (1989) is reviewed in some detail in the following text.

BOD loads are introduced to the model as so-called ultimate BODs, which are calculated from measured BOD5-values using a multiplier between 2 to 6.4. The lowest value is used for non-mill BOD; 4.0 for the CTMP mill BOD; 5.0 for the kraft mill BOD; and 6.4 for the background or non-point source BOD. The multiplier values have analytical support but they are not based solely on measurements. This is, in practice, the normal procedure and the effect of a possible wrong choice is not of great importance in this application. The justification here is that the mill BOD load is assumed to be absorbed from the water phase at a high rate, especially near the CTMP mill outfalls. The mechanism causing this, and the subsequent consumption of oxygen as sediment oxygen demand (SOD), is explained by Hamilton (personal communication) as a trickling filter-like effect. However, this theory lacks direct experimental evidence.

The major part of the DO decrease is caused by the SOD in this DOSTOC-application. This is clearly demonstrated in Figure 7/5 where the lower curve is the HydroQual final calibration curve for the #3-89 survey data; the middle curve represents a situation where BOD-loads for Weldwood and Millar Western are given value = 0; and the upper curve is for a no-mills situation where both the effluent BOD and site specific SOD are = 0. In the DOSTOC model there is no calculational relationship between SOD and BOD, but the values are assumed to be chosen by the user. For all the Athabasca calculations a linear relationship is used between mill BOD and SOD. Additional data on SOD and the balance between different sources for oxygen consumption in the Athabasca River during the winter low flow season (Casey 1989) became available after the calculations reported here had been completed. From a review of the data in Casey (1989), it is concluded that the modelling results reported here would not be changed significantly.

The planned ALPAC mill site is at reach #31 in DOSTOC (Figure 7/5). Because ice cover prevents reaeration in winter, the dissolved oxygen level in water entering the mill site is dictated by the upstream consumption. To clearly compare different BOD–load scenarios for ALPAC, the winter 7Q10–flow rate at Athabasca was chosen as the hydraulic basis. This flow rate provides the least dilution downstream from the ALPAC mill site and will therefore be called the worst case flow condition. It should be emphasised that the average winter low flow is substantially higher than the 7Q10 flow. In order to differentiate the impact of the ALPAC mill from that of the other four mills (Weldwood, Alberta Newsprint, Millar Western and Alberta Energy) four scenarios were calculated (see Figures 7/5 and 7/6):

In the calculations only the mill loadings and adjacent SODs are changed from those in the basic material received from HydroQual. Mill productions (ADt/d) used in calculations are: Weldwood–1100, Alberta Newsprint–700, Millar Western–680, Alberta Energy–350 and Alberta Pacific–1500.

The results by the scenarios are as follows:

1. No Mills

- Without any mill loadings, the DO will decline gradually from Hinton to the Grand Rapids, to the level of 8–9 mg/l (upper curve in Figure 7/5).

2. Four mills at 3 kg/ADt BOD load rate, ALPAC not included

- If the four mills are releasing BOD at 3 kg/ADt the organic load from the upstream mills is largely decomposed or sedimented out before reaching ALPAC and the DO level will decline to a minimum around reach #23 where some reaeration occurs. There is a small decline of about 1 mg/l between reach #23 and the ALPAC site. DO will reach a minimum of 6 mg/l at the ALPAC mill site and stay at this level until reaching the Grand Rapids. At the Grand Rapids reaeration causes a sharp immediate increase in DO by about 4.5 mg/l in all calculated scenarios (Figure 7/6).

3. ALPAC BOD at 1.5 kg/ADt and the other four mills BOD at 3 kg/ADt

This is the most important scenario.

- The additional BOD–load of 1.5 kg/ADt from ALPAC will result in an additional drop of approximately 1 mg/l until reaching the Grand Rapids. The DO remains slightly above 5.0 mg/l (Figure 7/6).

4. All five mills at 3 kg/ADt BOD load rate.

- This theoretical case is calculated to show the effects of non-compliancy (e.g. ALPAC effluent at 3.0 kg BOD/ADt) occurring simultaneously with 7Q10. This situation results in a further decrease the in DO level by another 1 mg/l, to the minimum of 4 mg/l, just upstream of the Grand Rapids.

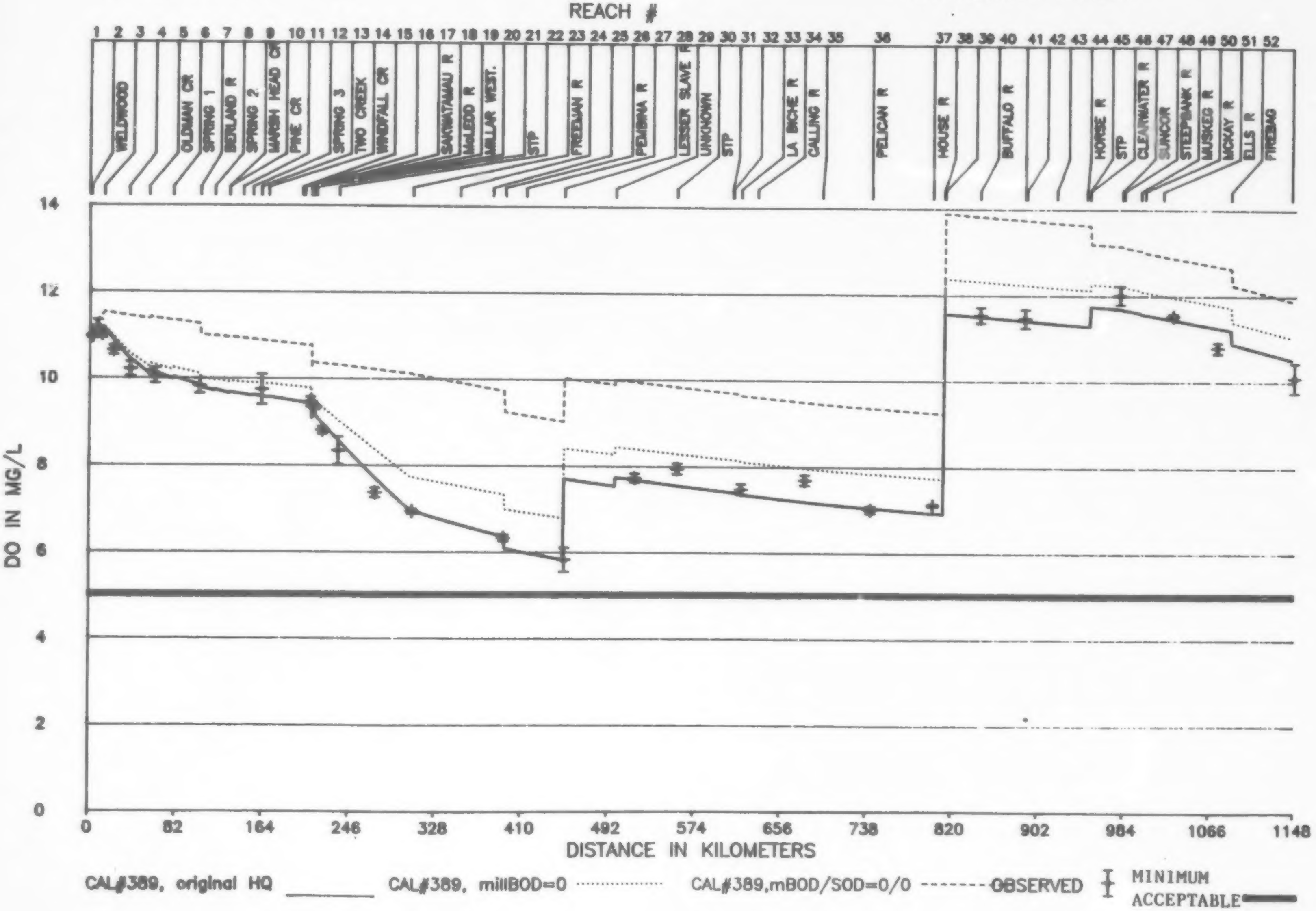
The DO calculations are also modelled to a more frequent low flow condition 7Q2. The flow pattern is calculated from Bothe & Siemonsen (1989) where 7Q10 was 75.9 m^3/s (50 % probability). The recalculation for the whole Athabasca River was made on the basis of Bothe & Siemonsen (1989) Table 3-1. The recalculated 7Q2 is somewhat conservative and gives DO-values which are too low rather than too high ones (difference in flow about 10 %). The results are shown in Figure 7/7. The difference in DO-values is approximately 1 mg/l higher for 7Q2 flow conditious than for 7Q10, with and without ALPAC.

The implications of the DO calculations are discussed in section 7.3.1.

FIGURE 7/5

DO CHARACTERISTICS

ATHABASCA RIVER



CALIBRATION #389, fractions of mill loadings (23.5.90 FPPRI)

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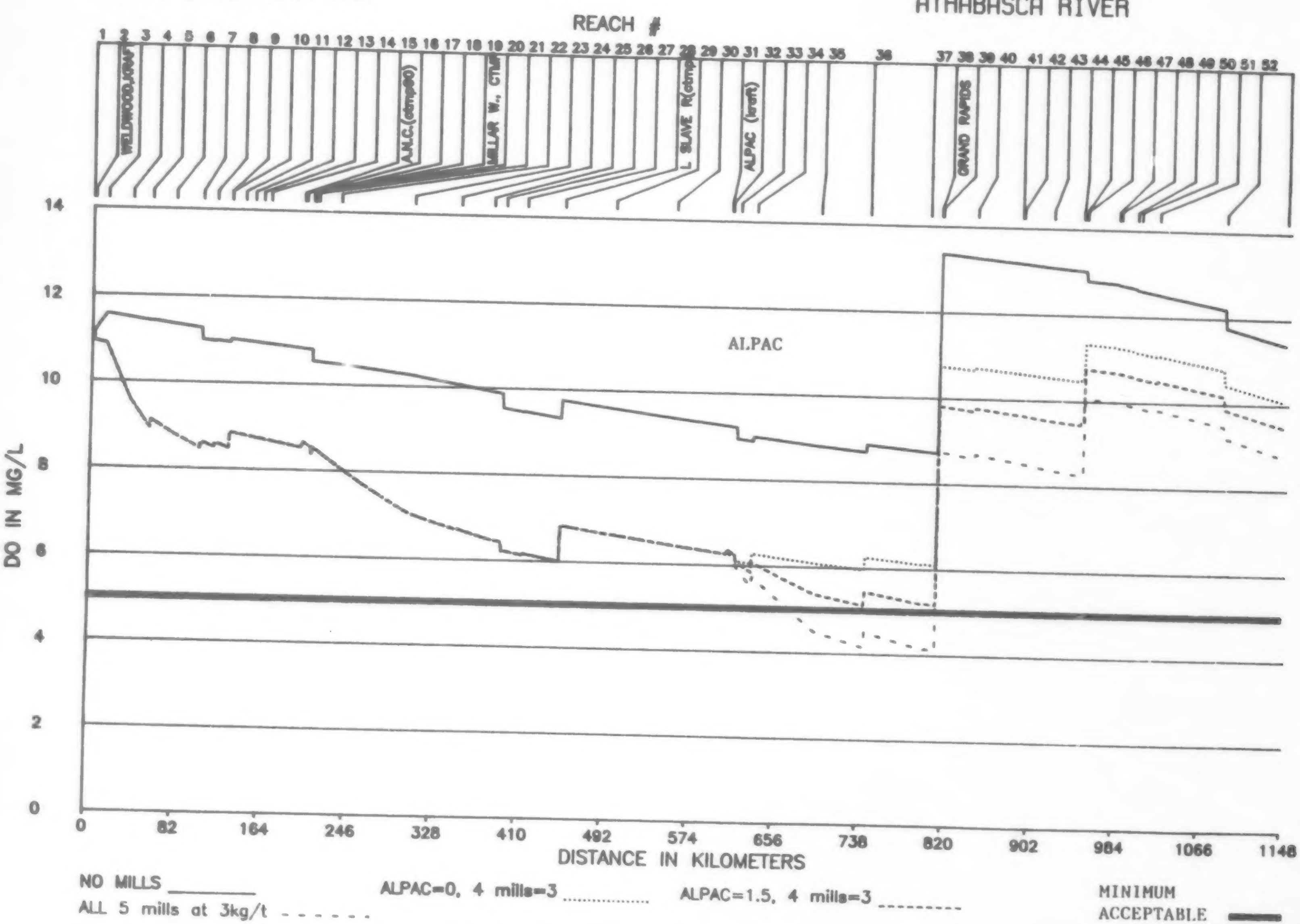
FIGURE 7/6

DO CHARACTERISTICS



SCENARIOS at ATHABASCA 7Q10 flow conditions (FPPRI)

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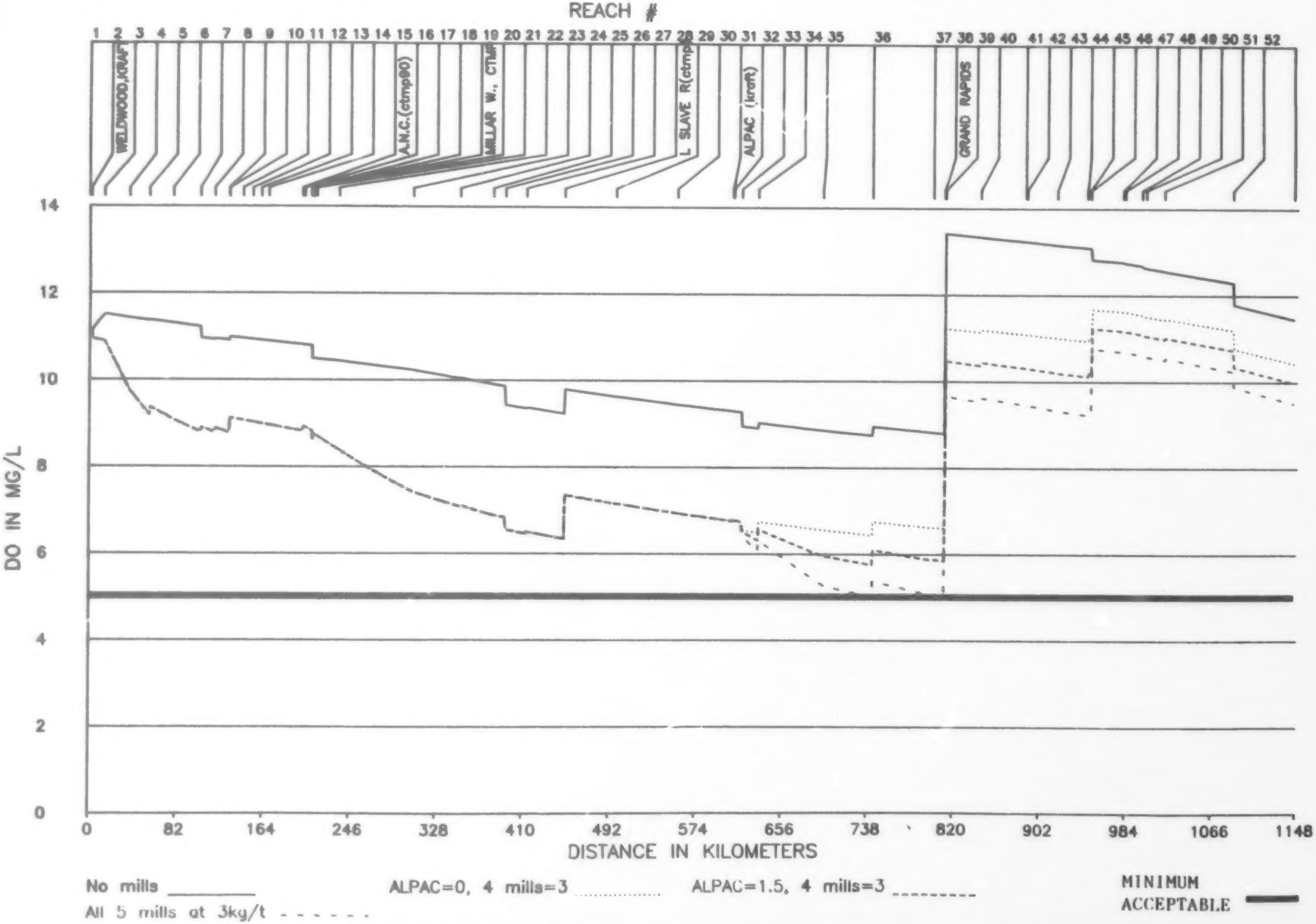
FIGURE 7/7

DO CHARACTERISTICS

ATHABASCA RIVER



SCENARIOS at ATHABASCA 7Q2 flow conditions (FPPRI)

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7.1.5
Nutrients

Phosphorus and nitrogen are generally considered to be the major nutrients that control the algal growth in an aquatic environment. Pulp mill effluents contain particulate and dissolved phosphorus and nitrogen, which originate from wood, and to lesser extent, process chemicals. Hence the effluent discharge may cause elevated levels of biomass production in recipient waters.

The concentrations of phosphorus and nitrogen in the Athabasca River water are highly variable, both seasonally and spatially. Total phosphorus ranges from 0.01 to 0.03 mg/l throughout the mainstem during the winter, and rises to over 0.2 mg/l during June and July along the lower half of the river. This indicates a tenfold increase in summer concentrations on average.

Seasonal variations in total nitrogen concentrations are not as wide as with phosphorus. The longitudinal range is from 0.1 to 0.6 mg/l, increasing from upstream sites to downstream sites throughout the year, with the exception of June and July, when the concentrations rise to about 1 mg/l along the lower half of the river (Hamilton et al. 1985).

Most of the total phosphorus and total nitrogen transport in the river occurs in particulate form during high flow season and is related to the flush of particulate matter from tributary flows and run–off (Hamilton et al. 1985, Alberta Environment 1990).

Table 7–7 presents the calculated pulp mill effluent contributions to the Athabasca River water concentrations of total phosphorus and with the theoretical assumption that only dilution affects the concentrations, and under the circumstance that both the present and future pulp mills are operating. The figures are estimated for various seasonal flow conditions and mainstem sites. Rough estimates of background concentrations of total phosphorus in the river water are presented for comparison.

It can be concluded that the effluent contribution to total phosphorus concentration is likely to be negligible on an annual basis, especially during high flow conditions in the summer months. Effluent contributions are a significant proportion of the total phosphorus only for the low flow conditions.

TABLE 7-7
The Contribution of Pulp Mill Effluents to Total Phosphorus Concentrations in the Athabasca River During Various Flow Conditions

Flow conditions	Effluent TOT.P[*] contribution mg/l	River background TOT.P level mg/l
Pulp mills upstream from Athabasca		
7Q10	0.042	
Winter average	0.024	ca. 0.02
Annual average	0.005	ca. 0.05
ALPAC at Athabasca		
7Q10	0.020	
Winter average	0.011	ca. 0.02
Annual average	0.002	ca. 0.05
All mills at Fort McMurray		
7Q10	0.029	
Winter average	0.019	ca. 0.02
Annual average	0.005	ca. 0.08
All mills at Embarras		
Winter average	0.016	ca. 0.03
Annual average	0.004	ca. 0.13

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[*] Total phosphorus (TOT.P)

The daily total phosphorus load of the pulp mill effluents is related to the inputs from municipal sewage plants and major tributaries in Table 7-8. The contribution of ALPAC to the total input of phosphorus from pulp mills in the Athabasca River would be about 30 %. The difference between tributary input and open water mainstem discharge indicates a high diffuse runoff of phosphorus.

TABLE 7-8
Daily Mass Load Estimates of Total Phosphorus and Total Dissolved Phosphorus in the Athabasca River System

	kg TOT.P/d	kg TOT. Dissolved P/d
Waste Water Input		
Expected pulp mill effluent load	282	
Municipal sewage load	70	
Tributary Input from Major Tributaries		
Mean of May, June, July, September, October 1984	3,900	700
Main Channel Export		
D/S Fort McMurray (Bitumount), Mean of February, March 1988	270	
Embarras		
Mean of June, July, September, October 1984	22,500	2,000

From: Alberta Environment 1989b
Noton et al. 1989
Hamilton et al. 1985

The estimated phosphorus load of ALPAC effluent is 90 kg TOT.P/d.

The annual total phosphorus and nitrogen discharge from the Athabasca River to Lake Athabasca can be roughly evaluated from the mass loads at the Embarras region. The discharge estimates are based on the daily mass loads in May, June, July, September and October of 1984 (Hamilton et al. 1985), and the months of February and March in 1989 (Noton and Shaw 1989). The discharges during the rest of the months have been evaluated according to monthly average flows, using the nutrient concentrations of the "closest" month. With the assumption that the daily average discharge represents the whole month it can be summarised that the annual total phosphorus discharge to Lake Athabasca would be at the Level of 4000 t/a and the total nitrogen discharge on the level of 16 000 t/a, respectively. Less than 5 % of the total phosphorus and less than 20 % of the total nitrogen discharge would occur during the ice covered months. The evaluation is extremely rough and may be overestimated due to the peak flows of suspended matter in the river system which do not last the whole month. For comparison, the estimated annual total phosphorus discharge from pulp mill effluents to the Athabasca River is about 100 t/a, approximately one-third of which would be the contribution from the ALPAC mill.

Contradictory estimates have been made of the transport of suspended matter from Lake Athabasca to the Slave River (Chapter 7.1.8). Hence, it is unclear whether most of the particulate nitrogen and phosphorus discharge settles in Lake Athabasca or is transported on to the Slave River.

The data of nitrogen loadings of pulp mill effluents are too scarce to be used for estimating effluent contribution to river water nitrogen. However, some results from bleached kraft pulp mill effluents treated in aerated lagoon indicate total N: total P and dissolved inorganic N:dissolved P ratios are close to 7 (Alberta Environment 1990), which is estimated to be closest to the optimal N:P ratio for algal growth when no other growth factors are limiting (Wetzel 1983).

The annual mean of the ratio of total N: total P in river water has been 4.3 at Athabasca and 6.6 at Embarras, the ratio being close to the optimal (Alberta Environment 1990). Hence, the discharge of pulp mill effluent nutrients are not expected to change nutrient ratio in the river. Neither of the nutrients stands out as the major limiting factor for the growth of algae.

7.1.6
Chlorinated Organic Compounds

AOX from pulp mill effluent can be considered as a rough indicator of potentially harmful chlorinated compounds in receiving waters. To date, the degradation of high molecular weight chlorinated compounds is poorly understood. Furthermore, it must be kept in mind that AOX is not linearly correlated to biological effects.

Low concentrations of AOX appear in natural water as a background level. The typical background concentrations in Scandinavian fresh water systems range from 10 to 30 µg/l (Wigilius et al. 1988, Carlberg et al. 1987, Priha et al. 1989). AOX concentrations in the Athabasca River System have not been measured.

The proposed ALPAC pulp mill effluent and the Weldwood pulp mill effluent AOX contributions to Athabasca River water during different river flow conditions are presented in Figures 7/8 to 7/10. The Slave River is considered in the estimate based on average annual flow. The estimates assume that only river dilution affects the AOX concentrations, which is the theoretical worst case situation. For ALPAC effluent AOX loading two different values are given: 1.3 kg/ADt as proposed by ALPAC, and

0.6 kg/ADt evaluated on the basis of best available technology. Concentrations for 7Q10 and winter flow conditions were not estimated for the sites located furthest downstream as the river discharge values for those were not available. It is assumed that the average winter and annual flow conditions are in most cases the appropriate basis for assessing the long-term environmental impacts as the 7Q10 flow rate occurs only very occasionally.

On the basis of the average annual flow, the concentrations of AOX diminish close to the background level downstream toward Fort McMurray, and only a negligible increase in the concentration is expected in the Slave River.

The transport, distribution and biological effects of trace chlorinated organic compounds are discussed in section 7.2.

FIGURE 7/8
Pulp Mill Effluent Contribution to AOX Concentration in River Water Under 7Q10 Flow Conditions (Extremely Low Winter Flow Period) when only Dilution is Considered

Estimated background concentration of AOX = 0.01 to 0.03 mg/l
(This is the level in some Scandinavian freshwater systems according to unpublished Swedish and Finnish measurements)

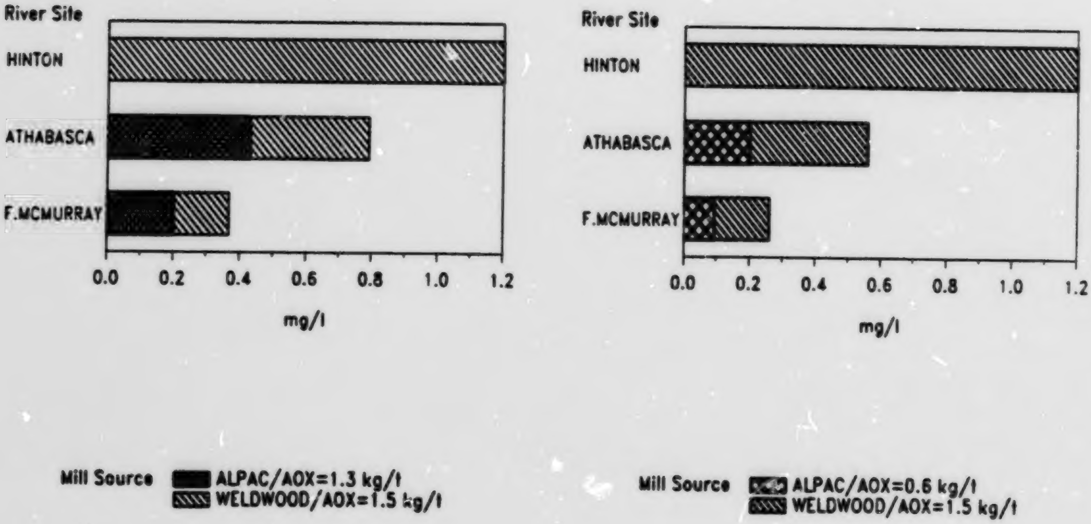


FIGURE 7/9
Pulp Mill Effluent Contribution to AOX Concentration in River Water Under Winter Average Flow Conditions when only Dilution is Considered

Estimated background concentration of AOX = 0.01 to 0.03 mg/l
(The level in Scandinavian freshwater systems)

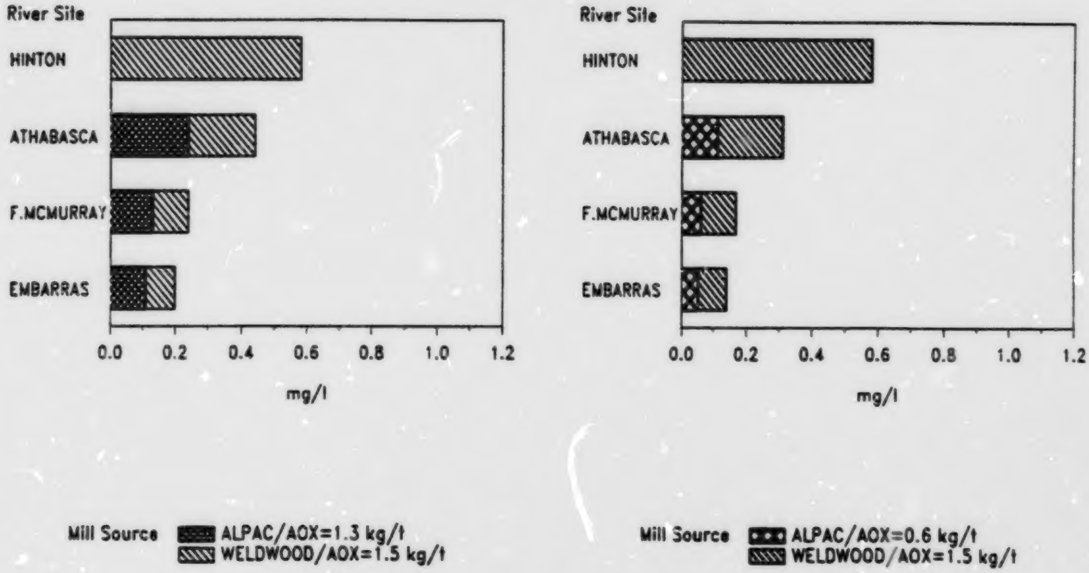
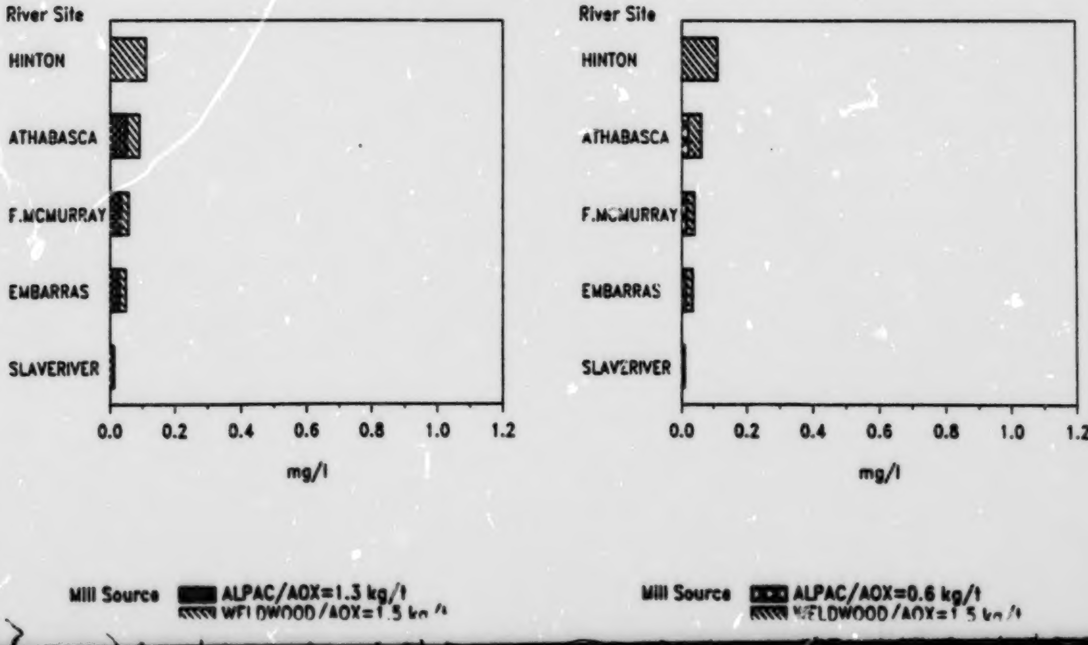


FIGURE 7/10
Pulp Mill Effluent Contribution to AOX Concentration in River Water Under Annual Average Flow Conditions when only Dilution is Considered

Estimated background concentration of AOX = 0.01 to 0.03 mg/l
(The level in some Scandinavian freshwater systems)



7.1.7
Suspended Solids and Color

There is a large scale variation in the concentration of the suspended solids (non-filterable residue) in the Athabasca River and its tributaries, both seasonally and spatially. Suspended solids are highly dependent on river flow discharges. During low flow conditions in winter months the concentration is approximately 10 mg/l along the mainstem throughout the river (Hamilton et al. 1985, Noton and Shaw 1989), whereas concentrations during the high flow season (June, July) rise to between 500 and 1000 mg/l in the downstream parts of the river and are between 50 and 100 mg/l in the upper parts (Hamilton et al. 1985). Tributary concentrations follow the same pattern.

The contribution of the proposed ALPAC pulp mill effluent discharge to suspended solids in the river during the 7Q10 flow conditions would be about 1 mg/l, which means an approximate increase of 10 % in "the worst case" winter conditions. The contribution of the four upstream pulp mills would be somewhat higher, because of the lower flows and wider discharge licenses. The increase of suspended solids in river water from pulp mill effluents during open water seasons is likely to be negligible, and be of minor significance throughout the year. The potential secondary effects of suspended solids will be discussed later.

Most of the color in water results from dissolved organic material (Wetzel 1983). A natural source of dissolved organic material is humic compounds. Pulp mill effluents contain highly-colored wood derivatives, such as lignin-related compounds.

The color values in the Athabasca River upstream of Hinton are low (<10 true color units (T.C.U.)), and do not vary seasonally. The Weldwood pulp mill effluent increases the color significantly immediately downstream of Hinton. However, the tributary color discharges are fairly high, especially during summer months due to high runoffs and the tributary discharges that control the color of the water in the lower half of the river. The annual average color at Athabasca is about 30 T.C:U. (Hamilton et al. 1985). Comparison of color in river water at Athabasca during the winter months (appr. 130 "pseudo" kg/d) (Noton and Shaw 1989) and the expected color discharge from the ALPAC effluent (43 "kg"/ADt) shows a contribution of about 50 %. During summer months ALPAC's contribution to water color will be of minor significance.

7.1.8
Sediment Transport and Sedimentation

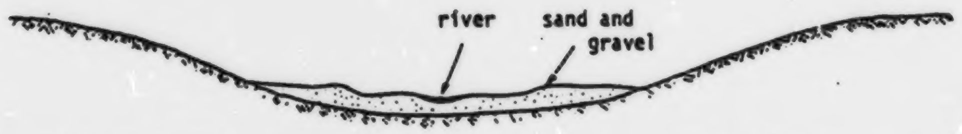
The Athabasca River transports large amounts of suspended matter which subsequently settles and forms deltas and lake sediment, further down the river system. The elevation of the land, following passage of the last glacier, has caused the river to scour and cut through a filled pre-glacial valley (Figure 7/11). The suspended material at this point along the river consists mainly of glacial lake deposited silt and clay, as well as finer till material. There is a smaller amount of suspended organic substances originating from biological activity in the catchment and in the river. Close to the river bed, coarser material is transported, such as gravel and stones. The Upper Athabasca River has been called a "wandering gravel river" (Neill 1973).

Further downstream, the slope of the river decreases (from >0.01 % to 0.003 %) and the river becomes less incised. By Embarras the river no longer flows in a typical valley; rather, it begins meandering over a wide flood-plain to the delta at Lake Athabasca. The river bed in the lower part of the Athabasca is static and consists of large gravel and rocks, covered by a moving bed comprising mostly fine sand and local gravel. By comparison, with the analogy made in the preceeding paragraph, the lower Athabasca River can be called a "wandering sand river". Contrary to the general trend found in most rivers, the size of the moving bed material increases in the lower part from Fort McMurray to Embarras, as the amount of clay in the sand decreases (Doyle 1977). This probably reflects the local river bank material which has been eroded.

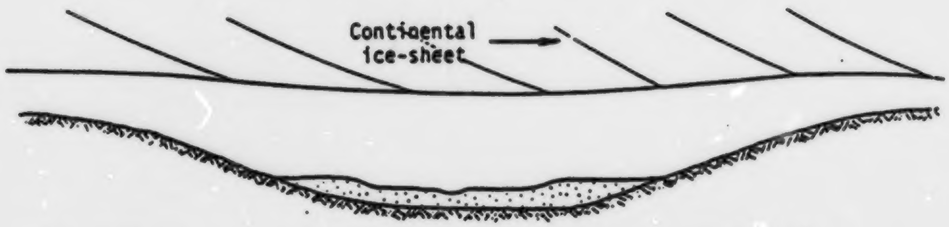
The Athabasca River empties through several channels into a large delta on the southwestern side of Lake Athabasca. There are four major channels in the delta; however, two of these (Goose Island Channel and Big Point Channel) discharge more than 70 % of the river water (Figure 7/12). During high flow, the delta is more or less flooded. During extreme low flow events water currents can only be detected in Big Point Channel (Harrington 1987). From Lake Athabasca, the Athabasca River water, mixed with lake water, meets the Peace River to form the Slave River. The hydraulics in the south-western part of Lake Athabasca are very complex, and the mixing of the river water in the outflow from the lake depends on discharges, winds, water currents, ice conditions, etc. A mean annual water balance for this area is shown in Figure 7/13, according to this estimate the Athabasca River accounts for about 50 % of the outflow of Lake Athabasca.

An important question in the context of this study is, how much of the sediment load in the Athabasca River is deposited in Lake Athabasca, and how much is transported further downstream to the Slave River.

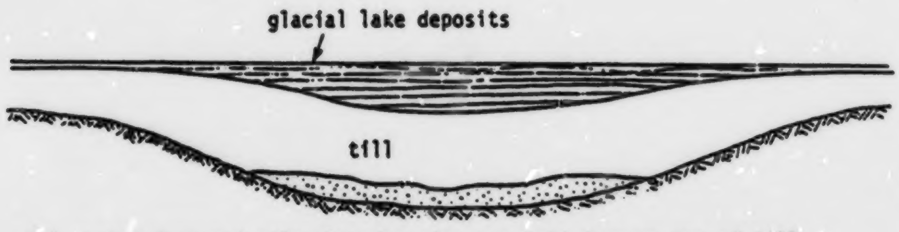
FIGURE 7/11
Inferred Sequence of Events Producing Observed Stratigraphy of Athabasca River Outcrops. From Neill, 1973


river
sand and gravel

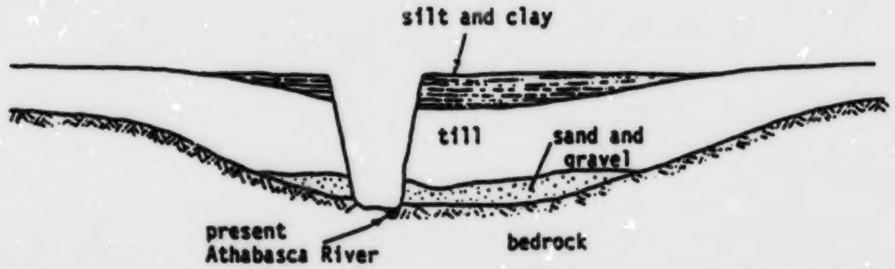
(a) Cross-section through wide valley before glaciation of Alberta


Contiaental ice-sheet

(b) Valley is more or less filled with till during ice-sheet advance; till settles under weight of ice


glacial lake deposits
till

(c) Lakes form and silt-clay deposits are laid down on top of till during recession and decay of ice-sheet


silt and clay
till
sand and gravel
present Athabasca River
bedrock

(d) Post-glacial Athabasca River cuts relatively narrow valley through up to four distinct categories of material. Depending on the location of the present valley with respect to the centre of the pre-glacial valley, one or more of the categories may be absent. At some points the sequence may have been complicated by ice-sheet re-advances.

FIGURE 7/12
Calculated Expansion of Inflow Jets in Lake Athabasca. From Neill et al. (1981)

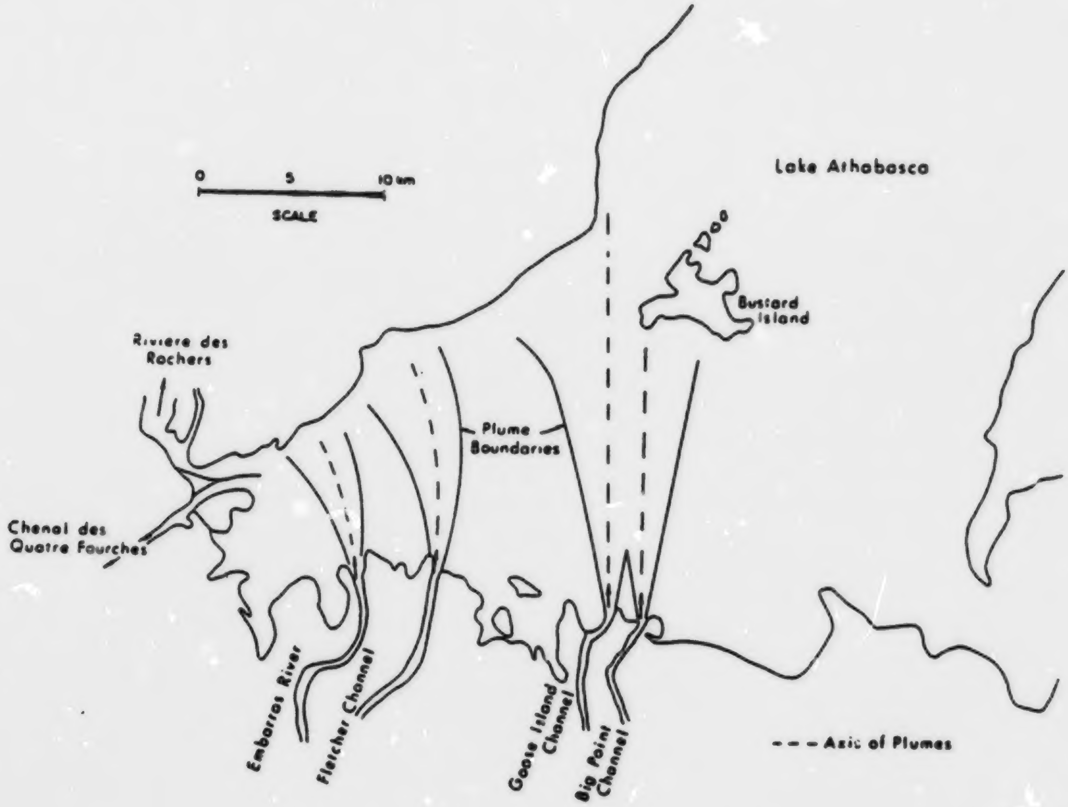
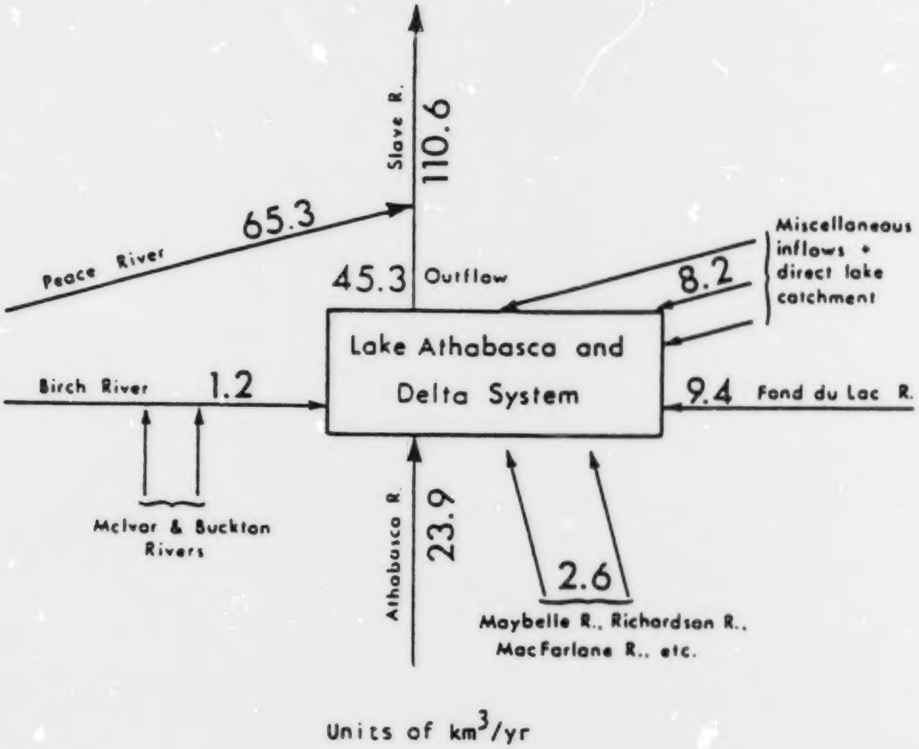

0
5
10 km
SCALE
Lake Athabasca
Bustard Island
Riviere des Rochers
Chenal des Quatre Fourches
Plume Boundaries
Embarras River
Fletcher Channel
Goose Island Channel
Big Point Channel
- - - Axis of Plumes

FIGURE 7/13
Mean Annual Water Balance, km^3/year, of the Lake Athabasca System. From Neill et al. (1981)


Slave R.
110.6
65.3
Peace River
45.3
Outflow
8.2
Miscellaneous inflows + direct lake catchment
Lake Athabasca and Delta System
Birch River
1.2
9.4
Fond du Lac R.
McIvor & Buckton Rivers
Athabasca R.
23.9
2.6
Maybelle R., Richardson R., MacFarlane R., etc.
Units of km^3/yr

Neill et al. (1981) report data on suspended sediment loads in the Athabasca River from 1969 to 1977. During this period, the range of sediment loads to Lake Athabasca was 3.3 to 12.9 million tonnes/year, with an average of 7.5 million t/year (the data were recorded at Fort McMurray over five-month period (May through September), but no significant transport was believed to occur during the rest of the year). Roughly one half of the annual sediment transport occurred during one month, usually June, July or August, and about 10 % of the annual transport often occurred during one day.

Based on the analysis of limited sediment data for 1973, 1975 and 1976, it was estimated that about 65 % (range 55–79 %) of the sediment inflow from the Athabasca River passes through to the Slave River via Rivière des Rochers (Neill et al. 1989). These values were also checked with grain size distributions which gave results in reasonable agreement with those listed above. The portion passing through consisted mainly of fine to medium silt plus clay, while coarse silt and sand were believed to be deposited in the Athabasca Delta channels or at the delta front in Lake Athabasca. These figures would seem to indicate that the Athabasca Delta is expanding in area by about 0.8 km^2 per year, which appeared to be confirmed by satellite images and earlier aerial photographs. However, during a flood period in June 1980, Neill et al. (1981) report that only 40 % of the sediment load of the river passed through Lake Athabasca. Harrington (1987) also made additional studies of satellite images and *in situ* measurements and found that the river water could reach further into Lake Athabasca than previously thought, but unfortunately no sediment budget was presented. The limited scientific information available indicates that the major part of the sediment load of the Athabasca River is deposited in the lake instead of passing through.

Most of the suspended material from the upper part of the river will be involved in sorption and desorption processes with the river bed, which are described in Chapter 7.2, and will only, to a smaller degree, reach the delta at Lake Athabasca.

7.2
Fate of Contaminants

7.2.1
Transport and Distribution of Chloro-organic Compounds and Resin Acids

Investigations of the environmental transport and distribution of specific contaminants discharged from pulp mills using conventional chlorine bleaching, have mostly been devoted to the study of polychlorinated phenolics and dibenzo-p-dioxins and furans. It has generally been assumed that the sorption behavior of these compounds to sediment particles is closely governed by their degree of hydrophobicity, i.e., their partition coefficient between n-octanol and water (P_{ow}). Sorption of a xenobiotic compound to the sediment phase will result in rapid removal of the chemical from the water phase. In some cases, however, the sediment sorption behavior of a chemical cannot be properly predicted from the P_{ow}, normally used in the initial assessment. One example is the polychlorinated catechols, which are quite tightly bound to the sediment phase - in fact, so strongly that they cannot be recovered by simple solvent extraction (Remberger et al. 1988). Thus the strong sediment-binding properties of xenobiotics is an important factor in their transport and bioavailability to various organisms.

Most of the xenobiotic compounds in pulp mill effluents will rapidly become associated with suspended particles. In order to predict the fate of these contaminants from the planned ALPAC mill, it is thus important to know how the suspended material is dispered in the river system. However, the dynamics of suspended sediment in rivers are quite complex because the suspended material is involved in continuous sorption and desorption processes with the river bed. Some of these processes are biotic, and the river bed acts much like a giant trickling filter. Other processes involve inflow and outflow of groundwater; in this case the river bed acts like a passive trap and a source of suspended material. Finally, chemical reactions and physical mixing can also occur between the suspended material and the bedload as mentioned above.

In attempting to predict the fate of the contaminants in pulp mill effluents that enter the Athabasca River, one may consider the extensive impact study that was conducted in the 1970s of the pesticide (or larvicide), methoxychlor (Haufe and Croome 1980). The objective of the study was to control black flies which were attacking cattle in the area of the Athabasca River. Fly breeding sites along the river, which were mostly downstream of the town of Athabasca, were treated with methoxychlor during 1974, 1975 and 1976. The pesticide was applied once or twice a year to maintain a concentration of 0.3 mg/l during seven and a half to fifteen minutes. The treatments were followed by extensive investigation of the distribution of methoxychlor in the river water, the river bed, and in the sediment of Lake Athabasca. The applied methoxychlor remained in emulsion close to the treatment area, but absorption to suspended particles took place rather quickly. With increasing adsorption, the methoxychlor was subsequently lost to the moving or static bed of the river, which resulted in a smaller amount of methoxychlor in the water and suspended material. The levels of methoxychlor in the river bedload were higher than those measured in samples of mud taken from sedimentation sites. About 17 months after the last treatment, the accumulation of methoxychlor was examined in sediments from nine sites the Athabasca delta and twenty-one sites at Lake Athabasca. No residues of methoxychlor were identified in any of the samples analyzed.

The maximum emission of chlorinated substances from the ALPAC mill is estimated to be approximately 500 t/year (as AOX). Generally speaking about 1 to 2 % of the AOX, thus max. 5-10 t/year, has hydrophobic properties and can be extracted and measured as extractable organic chlorine (EOCl). It seems plausible that the EOCl, as well as other components of the pulp mill effluent (such as resin acids and the extremely hydrophobic chlorinated dioxins), will behave much like the methoxychlor. If this is the case, the hydrophobic substances in the downstream vicinity of the effluent will be associated with the suspended material in the river water. Further downstream, association with both the suspended material and to material moving in the riverbed will occur.

While it seems plausible that most of the xenobiotics in the ALPAC mill effluent will remain in the Athabasca river bed, it is unlikely that these substances will reach 600 km downstream to the delta at Lake Athabasca, or further, to the Slave River System. This view is supported by the fact that no pollutants characteristic of pulp mill effluents could be detected during examinations of sediments from the Athabasca delta area during 1989 (Crowther et al. 1990), even though the Weldwood pulp mill at Hinton had been discharging effluents into the river since the 1950s. Dioxins and furans were barely detectable in one sample, but were present in sediment from a reference are at the Birch River delta. The levels of dioxins and furans were so low that the authors claimed that it "appeared to be a low level contamination over a very restricted region, or an experimental artifact". The composition of the dioxins did not match that of a pulp mill derived source (Crowther et al. 1990).

In sediments from receiving waters of bleached pulp mills one often finds gradients of EOCl and resin acids, with higher levels in those samples taken closer to the mills. In the case of the Athabasca River, however, it is doubtful that any gradients will be detected in the river bed downstream from the ALPAC mill due to the enormous amount of material in the moving river bed.

7.2.2
Persistence, Transformation and Degradation

The general view that chlorinated organic compounds are more persistent in the environment than non-chlorinated compounds is one of the rationales used by authorities in many countries to force the pulp mill industry to drastically reduce discharges of chlorinated organic material. Although this view may hold true in a majority of cases and, therefore, can be used as a general guideline, recent studies have clearly demonstrated that there are many exceptions.

The widespread, strong concern regarding the persistence of chlorinated organics in aquatic environments and therefore the potential hazard they represent, is largely based on earlier studies of polychlorinated compounds such as DDT, PCBs, toxaphene and, in relation to the pulp industry, 2,3,7,8-TCDD and -TCDF, and tri- and tetra-chlorinated phenols and guaiacols. This group of compounds is clearly quite persistent in the environment and, further-more, has other hazardous properties such as bioaccumulation potential and toxicity. It is also often argued that chlorinated organics are persistent, and hazardous, because they are man-made. It was generally believed that there was no natural biosynthesis of chlorinated organics, i.e., that all chlorinated organics found in the environment were of anthropogenic origin. However, natural production of organohalogens is now well documented for both terrestrial and aquatic environments (Siuda and de Bernardis 1973; Fenical 1981; Engvild 1986).

A structurally diverse range of halogenated metabolites may be produced by microorganisms, particularly by fungi and marine organisms (Neidlman and Geigert, 1986). The structural diversity is remarkable and includes halogenated aliphatic, alicyclic, aromatic and heterocyclic compounds. Organohalogens (measured as AOX) were detected in surprisingly high concentrations (30-380 µg AOX per gram) in organic matter, isolated from peat bogs in Sweden, remote from any industrial activities, (Asplund et al. 1988). The AOX concentration were particularly high in humic substances. Detectable levels of AOX were also quite conspicuous in old groundwater samples.

These observations clearly show that organohalogens are produced naturally in a variety of environmental compartments, and the question about persistence and the generally hazardous nature of such compounds must be put into perspective. An important conclusions is that not all chlorinated organics are automatically harmful; it is necessary to study each individual compound, and make specific assessments based on the relevant properties of that compound.

Returning to the problem of chlorinated organics in pulp mill effluents, it is important to remember that an alert, issued some years ago, stating that these compounds, as a group, have a severe detrimental impact on the environment, was based on studies of the composition of pulp mill effluents at that time. It is clear that using conventional chlorine bleaching techniques with an inefficiently washed pulp, having a high kappa number, produced substantial amounts of highly chlorinated aromatic compounds (such as tetra–, penta– and hexachlorodioxins and furans; as well as tri– and tetrachlorophenols and –guaiacols) (IPK 1982).

However, analysis of current effluents, from processes using extended cooking, oxygen delignification, efficient washing, and a high substitution of chlorine with chlorine dioxide, shows that: (a) phenolic compounds with a lower degree of chlorination exceed those with three or four chlorine atoms per molecule; (b) effluents are no longer dominated by chloroguaiacols and chlorocatechols, but are increasingly dominated by low–chlorinated vanillins; and (c) polychlorinated dioxins and furans have virtually disappeared from the effluents discharged from most pulp mills operating today (Strömberg et al. 1990).

This substantive change in the composition of chlorinated organics in effluents (in addition to the drastic decrease of the total AOX) has one further important implication: the remaining chloro–organic compounds are much more readily biodegraded (Österberg 1984). This means that external treatment of the effluents by means of activated sludge or in an aerated lagoon, will reduce to low levels the residual amounts of AOX being discharged into the receiving water. These residual compounds will be further degraded in the receiving environment. It should, however, be noted that high–relative–molecular–mass materials in spent bleaching liquors are probably biologically rather inactive, because they cannot penetrate cell membranes of living organisms. It is an open question whether and to what degree these materials are broken down biologically and chemically to form low–relative–molecular–mass compounds possibly having detrimental biological effects (Kringstad, 1984). As the structure of chlorinated high–molecular–weight material has not been resolved, studies on its biodegradation and biotransformation are limited. Nonetheless, this material is susceptible to both microbiological and chemical attack (Neilson et al. 1990).

Another important aspect of discharges of chlorinated phenolics is the transformation of these compounds by microorganisms in the environment (Neilson et al. 1984; Allard et al. 1987). From an environmental impact point of view, the most interesting transformation is the O–methylation reaction, producing metabolites which are more hazardous than the original compounds. It has been clearly shown that O–methylation of halogenated phenolics is a ubiquitous reaction in the environment, and could be regarded as an alternative to degradation. The environmental significance of O-methylation comes from the fact that the metabolites (halogenated anisoles, in the case of O-methylation of halogenated phenols, and halo-veratroles from haloguaiacols) are persistent. The metabolites are much more bioaccumulative than the parent compounds – in some cases exert specific toxic action on fish (Neilson et al. 1984) – and have a strong taste and odor (Veijanen et al. 1988). This particular property of chlorinated phenolics is another good reason for minimizing to as low a value as practically possible, the amount discharged into the aquatic environment.

A further group of compounds, which are discharged from pulp mills in considerable amounts, but which so far, have not been considered very persistent in the environment, are the resin acids. This view will have to be altered somewhat since high concentrations of resin acids and chlorinated resin acids have recently been found in the sediments of Swedish lakes receiving discharges from pulp mills. Sediments in Lake Vanern in Sweden contained high levels of resin acids equal to the content of EOCl (Grahn and Sangfors, in preparation). Pulp mills have discharged such substances into the lake since the 1940's when concentrations of chlorinated phenolic substances were much lower. The total amount of EOCl in the surface sediment of the lake was calculated to be 114 tons, of which 3.6 tons were of natural origin. The content of chlorophenolics (phenols, guaiacols, catechols) was 0.85 tons, whereas the content of resin acids was 45 tons.

Interesting to note in this respect is that chlorinated phenolics only constituted a small fraction of the total amount of EOCl. The water residence time of the lake is 8.8 years, and if the chlorinated phenolics were very persistent the levels would have been higher. Thus it can be argued that chlorinated phenolics are effectively broken down over time.

7.2.3
Bioaccumulation – Internal Dose

For most neutral organic compounds, their n-octanol/water partition coefficient (P_{ow}) is a good predictor of the bioconcentration potential. However, for polar compounds, like the chlorinated phenolics and the resin acids in pulp mill effluents, the P_{ow} value is of limited help in predicting the bioconcentration factor. Some of the neutral, chlorinated compounds related to pulp mill effluents have a very high bioconcentration potential, which can be demonstrated by the following examples of $\log_{10}$ bioconcentration factor BCF (related to fish) (Nelson et al. 1984).

Compound	BCF
2,4,6-trichloroanisole	3.9
3,4,5-trichloroveratrole	3.3
tetrachloroveratrole	4.5
2,3,7,8-TCDD	4.6

Neutral chlorinated compounds, however, are relatively scarce in pulp mill effluents, which are largely dominated by polar substances. Most of these do not show any strong tendency to become concentrated in the fatty tissues of fish or other aquatic organisms. In spite of the very high bioconcentration factor of e.g., 2,3,7,8-TCDD the residence time of this compound in the fish body is not very long. The biological half-life of this compound in rainbow trout has been determined to be 15 to 48 days after the fish were returned to uncontaminated water (Mehrle et al. 1988). Clearly, it is not easy to monitor the occurrence of these compounds by taking samples of fish fat and analyzing them for chlorinated phenolics or resin acids for example. Therefore, a new, efficient tool for monitoring these compounds had to be developed. The demand was met by (among others) Oikari in Finland (Oikari & Kunnamo 1984).

For several years Oikari and co-workers have used the presence of conjugated phenolic substances and resin acids in the bile of fish as a tool for monitoring the exposure situation and the distribution of specific pulp mill substances in water courses. The reason for using fish bile as a measurement is that these compounds are concentrated in the bile before being excreted through the intestine and out of the body. Bile analysis is much more accurate than water analysis due to the high concentration of conjugated phenolic substances in fish bile.

The levels of the conjugated, water-soluble chlorophenolics and resin acids constitute roughly 95 % of the total bile content. By comparison, the levels measured as free, unconjugated substances in other parts of the body are only a fraction which are rapidly excreted from the fish in clean water (Oikari & Holmbom 1986). From this it is evident that chlorinated phenolic compounds and resin acids cannot be considered as bioaccumulative in the sense that the levels would increase indefinitely in the organism under continuous exposure since an effective excretion system is present in the fish.

As to the question whether toxic compounds from pulp mills will cause toxic effects in general in the Athabasca River and what the contribution of the planned ALPAC mill will be, cannot be answered explicitly since the present impact of the discharges from the Hinton and White Court mills is not known.

Analyses for the presence of chlorinated phenolic substances in fish tissues (burbot liver) from the Slave River varied between 20 and 750 ng/g based on fat weight. As a comparison, results from Sweden showed total levels of 1000 ng/g wet weight (corresponding fat weight with about 15 % fat content, 6700 ng/g) in liver tissue from perch recorded from an area outside two pulp mills (Anon. 1982). Effects of fish populations on the same area have not been recorded (Grahn and Lehtinen 1988).

The isomers with the highest concentration in burbots from the Slave River were tri–chlorinated (2,4,6) and tetrachlorinated phenols. The pulp mill specific chlorinated guaiacols were low, i.e. not exceeding 7 ng/g. Since guaiacols usually occur in much higher concentrations than chlorinated phenols in bleached pulp mill effluents (see Lehtinen 1989) the high levels of chlorinated phenols (mainly 2,4,6–trichlorophenol) in the liver of burbot from the Slave River do not seem to be of pulp mill origin. In some studies in the Finnish lake districts, including unpolluted areas, the levels of chlorinated phenols upstream from pulp mills varied between 270 and 580 ng/g in winter, and 40 to 180 ng/g in summer on a freshweight basis in the liver of pike (Esox lucius) (Priha, personal comm.). In the light of this the levels of chlorophenolic substances in fish from Slave River cannot be considered as abnormally high because even in unpolluted Finnish lakes the levels of these substances were higher than in the Slave River.

Recent preliminary results (March 1990) of water analyses for chloroguaiacols showed an increase in the concentration of these substances in the Athabasca river water some 900 km downstream of the point where the mill effluents are introduced into the river (Brian Brownlee, Natl. Water Research Inst. Burlington Ontario, personal communication). The levels are not high compared to analyses performed in Nordic water courses, however, the distance they were carried is noteworthy. Similarly, the chloroguaiacols levels in fish tissue taken from the Slave River were low and show that these compounds do not accumulate at any considerable rate.

7.3
Effects

A wide variety of sublethal effects is studied in aquatic toxicology because different categories of effect are useful in different ways. In general, if one is interested in effects that are meaningful to the success of an organism in its environment, then one should refer to the "levels of integration", specifically to effects on the whole organism, groups of organisms, or communities of organisms. If one wishes to understand the mechanism by which an effect is caused, then one should look at effect found within the organism, e.g. physiological and biochemical changes, tissue damage, etc. (Sprague and Colodey, 1989).

When considering the effects of the proposed ALPAC mill there is a lack of information on fish populations and fish habitat, as well as fish physiology in the Athabasca River.

7.3.1
Fish Ecology and Fisheries

Major fish species of the Athabasca River Basin are listed in Appendix IV.

As mentioned in the Nov. 18, 1989, submission of The Department of Fisheries and Oceans, and the Department of Environment fish life histories and their habitat requirement are not well known throughout the reaches and tributaries of the Athabasca River above the Grand Rapids. This is especially true for the reaches immediately downstream from the proposed ALPAC pulp mill to the Grand Rapids. However, much more is known about the fish and their habitat requirements downstream of the Grand Rapids and into the delta (Wallace and McCart 1984).

The mainstem of the Athabasca River, from the community of Fort Assiniboine to the Grand Rapids, is the least known section of the entire Athabasca Basin. By contrast major studies have been conducted, in the reach from the Grand Rapids to Fort McMurray and downstream to the delta and Lake Athabasca (Wallace and McCart 1984; McCart et al. 1982). The Athabasca mainstem above and below Cascade Rapids serves as a major spawning area for several species of fish, including populations of lake whitefish, which reside in Lake Athabasca and migrate upstream during the summer. These fish spawn in the fall, in the vicinity of Mountain and Cascade Rapids, upstream of Fort McMurray. MacCart et al. (1982) estimated that a minimum of 300,000 and a possible maximum of over a million lake whitefish spawn in this area. The river spawning population is a relatively fast-growing one, lives to the age of about 20 years; thus differing from the lake spawning population which grows more slowly but lives longer. The Athabasca River below the Grand Rapids is also known as a spawning area for longnose sucker, walleye and possibly trout perch.

Fish migrations and overwintering sites of different fish species are also known from the area between Grand Rapids and Lake Athabasca and the delta. As to other part of the Athabasca River there is some knowledge of the existing fish species in the mainstem and tributaries.

There are few, if any, studies of fish migrations between the mainstem and the tributaries of the Athabasca River. Fish reproduction areas and overwintering areas in the Athabasca River and its tributaries, excluding downstream of the Grand Rapids, are not known.

Twenty-five fish species have been identified in the Slave River (R.L. and L./EMA 1985). Most of these species are found in the area which extends from the Slave Delta upstream as far as the Rapids of Drowned at Fort Smith. The rapids apparently presented a barrier to upstream movement. The most abundant fish species as a whole in the Slave River, (excluding the smaller fish species) is goldeye, followed by lake ciscoe and northern pike. Lake whitefish and other autumn-spawning species, like inconnu, enter the Slave River in late summer and breed beneath the rapids. After spawning they return to the Great Slave Lake. The model is very similar to the breeding behavior of autumn-spawning fish from Lake Athabasca.

The impact of the future ALPAC pulp mill on the potential loss of fish habitat and productive fish capacity, as well as the effects on fisheries, cannot be determined due to lack of information on baseline fish population and critical fish habitat in the Athabasca River mainstem and tributaries. This is especially true for the area between the proposed mill site and the Grand Rapids. The known breeding areas below the Grand Rapids are situated about 200 km downstream of the proposed mill site. When considering the 7Q10 flow of 53.6 m^3/s at Athabasca and the proposed effluent flow of 0.95 m^3/s, the concentration of effluent close to the outlet will be about 1.7 %. The effluent concentration will then be diluted to concentrations below 1 % upon reaching the breeding areas.

Freshly fertilized rainbow trout eggs, placed in solutions containing 5.6 to 100 % biologically treated bleach kraft mill effluent (BKME), developed in a fashion similar to the control eggs when the effluent concentration was less than 32 % (NCASI 1982). Artificial stream studies have not shown any deleterious effects to warmwater and coldwater fish production or reproduction in biologically-treated BKME at typical dilutions. However, effluents from a pulp and paper mill, with conventional bleaching and an external effluent treatment in an aerated lagoon, were shown to affect northern pike eggs in concentrations as low as 0.5 % or greater (Tana and Nikunen 1986).

Northern pike from the Athabasca Basin are known to spawn in marshy areas adjacent to the river and in some tributaries (Wallace and McCart 1984). Spawning is thought to occur in late April and early May. The flow of the Athabasca River has increased considerably from the winter lows during that time as has the dilution of the ALPAC effluent. This means that the effluent from the proposed ALPAC pulp mill with oxygen prebleaching and activated sludge effluent treatment is likely to have no evident effect on the development and survival of pike eggs or any other fish eggs in the known spawning areas. Spawning in these areas is occurring during periods other than those with critically low flow conditions. This means that the sensitive stages of reproduction (fertilization and hatching) take place when the effluent concentration downstream of the Grand Rapids is far below 1 %.

Impact of Dissolved Oxygen on Fish

Dissolved oxygen (DO) is required by aquatic organisms for aerobic respiration. At low concentrations, it can become a limiting factor for maintenance of aquatic life. The lower lethal limit is species–specific. The effects of toxicants may be magnified, if the aquatic organism is under stress due to low dissolved oxygen. There are a number of surface water quality guidelines and objectives dissolved oxygen. The current Alberta water quality objective (ASWQO) is 5 mg/l. However, this standard is now under review and will possibly be replaced with a higher value of 6.5 mg/l (Noton and Kemper, pers. comm.). Current Canadian federal water quality guidelines (CWQG) are 9.5 mg/l for sensitive salmonoid species and lifestages.

The dissolved oxygen concentrations in the Athabasca River and the modelling of it has been dealt with in section 7.1.4 of this report. According to studies made by Alberta Environment (Noton and Shaw 1989) the DO concentration in the Athabasca River was decreasing from the point at Whitecourt and reached a minimum of about 5.5 mg/l within Lesser Slave River confluence. According to the dissolved oxygen model calculation for this report, the DO concentration could decrease to close to 5 mg/l when ALPAC and the other mills planned are in operation at maximum capacity. The DO level should not drop below 5 mg/l if all of the mills operate within their licensed effluent release limits (see Section 7.1.4 and Figure 7/6). In addition, there is provision made in the operating licenses for the mills, that lower BOD–limits will be applied to the effluents during critically low flow conditions. The low oxygen level will extend from the proposed ALPAC mill site to Grand Rapids and will cause impacts to aquatic life in that reach. After Grand Rapids the DO concentration will increase to a level of approximately 9–9.5 mg/l even during low flow conditions with all proposed mills in operation.

Fish spawning and the early lifestages of fish are considered to be the most sensitive to low DO concentrations. The known spawning areas in the Athabasca River are situated downstream from Grand Rapids where DO concentrations, even during low winter flow conditions, are above 9 mg/l. This means that dissolved oxygen is not a problem for species breeding in areas between Grand Rapids and Lake Athabasca. The spawning areas between Grand Rapids and the proposed ALPAC mill site, and even further upstream to Hinton, have not been identified. The DO concentrations in this area are expected to decrease to between 6 to 8 mg/l after construction of the ALPAC mill and will further decrease to about 5 mg/l for 7Q10 flow conditions if all of the mills continued to release effluents at maximum permissible level. According to the model, the DO concentrations will drop to 8 mg/l even when no mills are operating. Thus, the successful breeding of the most sensitive salmonoid species is in any case doubtful at this part of the river.

The DO demand differs for different fish species, and depends on their breeding habitats. The breeding grounds and the sediment oxygen demand must also be considered when the sensitivity to water DO concentrations are discussed. At present the fish species living in the Athabasca River have to breed either in the mainstem or in the tributaries in order to maintain their stocks. The breeding areas and the breeding migrations in river reaches with low oxygen levels have not been studied, and it is felt that a major investigation is warranted. It is quite obvious that once all proposed mills are operating DO concentrations during low winter flows in the Athabasca River will be of concern. The present lack of information precludes a proper impact assessment in relation to this matter.

Fisheries

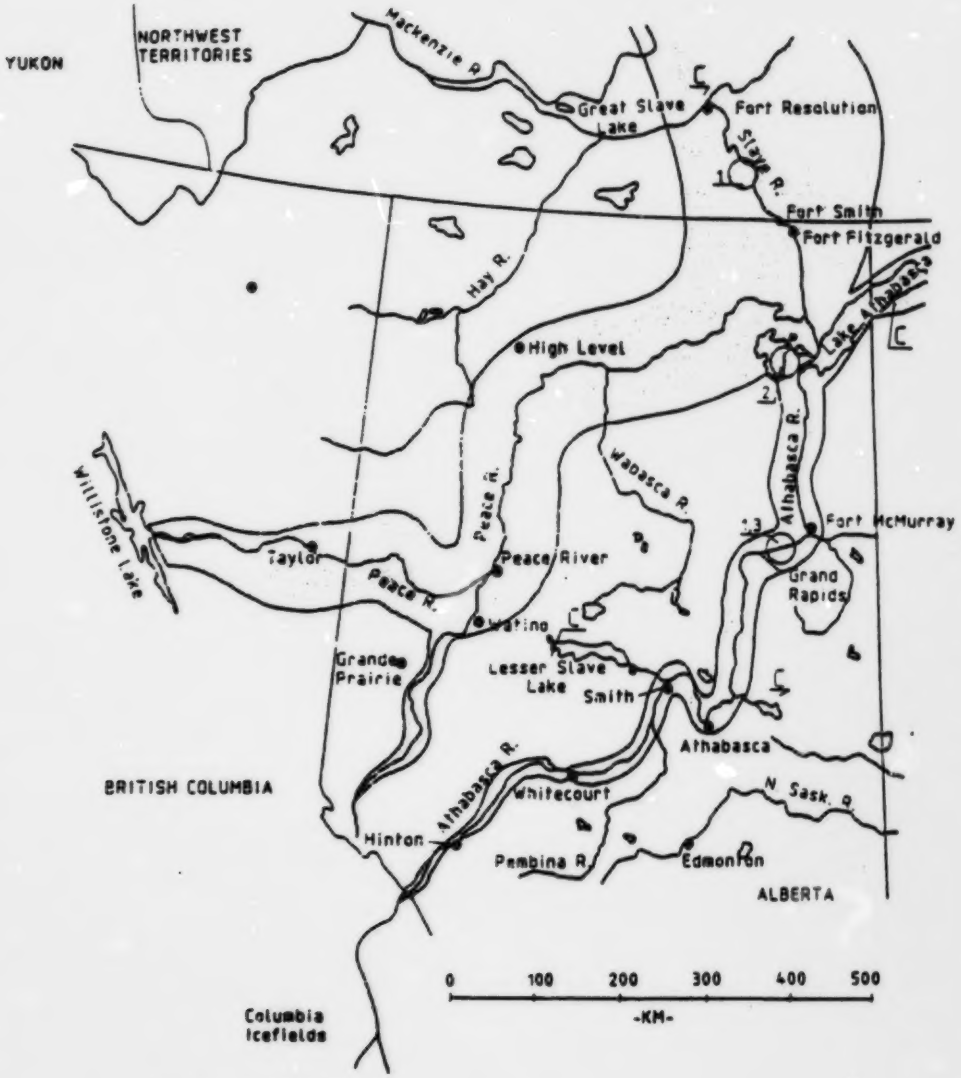
The pressure of urban, agricultural and industrial growth has already taken its toll on the fish habitat and fish populations of the region (Wallace and McCart, 1984). The Athabasca Basin provides sport fishing opportunities for almost 9 % of Alberta's licensed anglers. The mainstem of the Athabasca and tributary rivers, such as the Berland, McLeod, Pembina and Clearwater, supply important, and in many cases well-utilized sport fishing opportunities. In the reaches below the proposed pulp mill sport fishing is mainly concentrated in the tributaries, with very little in the mainstem.

Among sportfish, Arctic grayling, northern pike, yellow perch and walleye are the most widely distributed in tributary streams. Lake whitefish, which is an important domestic fish, is widely distributed, but generally restricted to confluences along the Athabasca River.

The commercial fishing is concentrated in Lesser Slave Lake and Lake Lac La Biche. The areas for commercial fishing and major spawning areas are shown in Figure 7/14. The range from coldwater to warmwater fish habitat, which occurs throughout the Lesser Slave Sub-Basin, results in a diverse fish population. The Lesser Slave Lake fishery is the oldest and most productive commercial fishery in the Athabasca Basin. In studies referenced by Wallace and McCart (1984) there were no comments of possible effects of the pulp industries upstream of the Athabasca River from Lesser Slave River. The principal commercial fish species in Lake Lac La Biche have been lake whitefish, lake trout and ciscoes. Lac La Biche is one of the most important commercial fisheries in the entire Athabasca Basin, and one which has been exploited for well over 40 years (Wallace and McCart 1984).

Domestic fishery in the Slave River is very selective, and in catches, lake whitefish is the most abundant, followed by burbot and inconnu. There is a large commercial fishing industry in Great Slave Lake. This commercial fishery is the only one with a significant export component. According to information from the Department of Fisheries and Oceans (1988) five species are exported, of which lake whitefish is most abundant, followed in order by lake trout, northern pike, inconnu and walleye. Sport fishing in the Slave River is of minor importance compared to the Athabasca River.

FIGURE 7/14
Areas with Commercial Fishing and Known Fish Spawning and Migration Areas (from Wallace and McCart, 1984)


YUKON
NORTHWEST TERRITORIES
Mackenzie R.
Great Slave Lake
Fort Resolution
Slave R.
1
Fort Smith
Fort Fitzgerald
Lake Athabasca
C
C
C
C
Hay R.
High Level
2
Athabasca R.
Wabasca R.
3
Fort McMurray
Williston Lake
Taylor
Peace R.
Peace River
Peace R.
Grand Rapids
Watino
Grande Prairie
Lesser Slave Lake
Smith
Athabasca
Athabasca R.
Whitecourt
N. Sask. R.
BRITISH COLUMBIA
Hinton
Pembina R.
Edmonton
ALBERTA
0
100
200
300
400
500
-KM-
Columbia Icefields

C = areas with commercial fishing

1. Known spawning area of lake whitefish, lognose sucker and probably walleye
2. Probable spawning area of goldeye
3. Lake whitefish and walleye are known to migrate to this area; northern pike is known to spawn in tributaries.

The species fished commercially in Lesser Slave Lake and Lake Lac La Biche are mainly lake whitefish, walleye, pike and lake trout. These species are known to spawn mainly in the tributaries of the lakes and there is little or no evidence of large fish migrations between the lakes and the mainstem of Athabasca River. According to Wallace and McCart (1984) growth of lake white fish in Lac La Biche is similar to that reported for Cold Lake and Lesser Slave Lake. The lake whitefish inhabit deeper water and will move to shallower reaches with sand–gravel substrates to spawn. Walleye, which also frequent the deeper waters of the lake, move into shallower areas and inlet creeks to spawn at night. The weedy embayments and adjacent sloughs are used by pike for spawning, as are some sand–gravel lake edge areas by whitefish. The precise locations are poorly defined at present and there is little or no evidence of large fish migrations between the lakes and the mainstem of Athabasca River. As there is no evidence of migration of the commercial fish populations from the lakes to the Athabasca River the commercial fish stocks will not be exposed to pulp mill effluents. Commercial fish populations in Lake Athabasca and Great Slave Lake are not at risk from the pulp mill related toxicants because of the great dilution factor and the degradation of toxicants before reaching the lakes.

7.3.2
Sublethal Effects of Fish Physiology and Fish Population

Chlorinated phenolic compounds are toxic to aquatic life, notably to fish and such compounds could be responsible for effects noted in laboratory and in the field experiments with full bleach kraft mill effluent BKMEs. Several projects undertaken during the 1970s and 1980s were designed to provide data that would support this premise (see Lehtinen 1989; Tana, 1988). In a recent Swedish government project "Environment–Cellulose" physiological responses like changes carbohydrate metabolism and induced hepatic biotransformation enzymes production were obtained in fish from the receiving water body outside a bleached kraft pulp mill (Anderson et al. 1987).

It was further claimed that the chlorinated organic matter was probably the reason for the effects noted. The effects were seen as far as 10 km from the mill discharge at dilutions of the effluent in the order of 1000 times. The mill in question had efficient internal control measures but primitive external effluent treatment. Similar effects outside a mill with unbleached production were less prominent, which was taken as evidence that the effects noted for the previous mill were due to chlorinated organics.

Parallel experiments using the model ecosystem technique (Notini et al. 1975) showed that process modification inside the mills, including introduction of oxygen pre–bleaching, high substitution of chlorine with chlorine dioxide, and external treatment, practically eliminated physiological effects in fish (Lehtinen et al. 1990; Lehtinen, 1989). It is also noteworthy that evidence for toxicity from chlorinated phenolic substances was not obtained.

Effects of 4,5,6-trichloroguaiacol (TCG) were studied by Rosemarin et al. (1990) in model ecosystems during a 16-month continuous exposure to three different concentrations (1, 10 and 50 µg/l). In this experiment it was found that only 0.5 % of the total substance added was recovered in the system. Of this loss, 99 % was associated with the sediment. The bioconcentration factor of TCG and metabolites from water was 700 in fish, and less in algae (Rosemarin et al. 1990). However, the number of fish produced in the model ecosystem or the total biomass was not affected. The only dose-related effect noted was a reduction of mean size in the largest size class after 16 months of exposure. The results indicate that fish populations would not, to any large extent, be affected by the presence of such substances in the water.

Recent field investigations, including fish population studies; fish physiology; and analyses for conjugated chlorophenolics and resin acids in fish bile outside Swedish kraft pulp mills (with and without treatment); also point in the same direction; namely, no significant effects were detected on the constitution of the age classes (Lehtinen et al. 1988; Tana et al. 1988, Hansson 1986). The field investigations included some mills that have operated for a long time, discharging effluents into restricted receiving waters with a high exposure of the fish populations (Tana et al. 1988). The same fish populations in the vicinity of the older mills showed only small signs of physiological responses.

Based on the literature cited above, it is evident that the hazard to fish populations, from chlorophenolics in concentrations normally occurring in the receiving waters outside modern bleach plants, may be regarded as negligible. Moreover, despite through investigations, there is no evidence that these particular substances would be responsible for the effects seen in fish exposed to full BKMEs. On the other hand, resin acids close to mill discharge sites may be important cytotoxins. In this respect they may be responsible for some initial tissue damage and thus promote a decreased capability to excrete other substances. In old mills with high black liquor carry-overs, poor pulp wash, etc. these substances may pose a problem to fish due to their relatively high concentrations.

Polychlorinated Dibenzodioxins and Dibenzofurans

A few years ago polychlorinated dioxins and furans were found to be formed in the bleachery (see for example de Sousa et al. 1989; Kringstad et al. 1989). The total amount discharged from Swedish mills in 1987 was in the order of 20 g per year, but in 1989 this amount was reduced to about

6 g (Eadon equiv.). From the aquatic toxicological point of view the effects of chlorinated dioxins and furans are hard to assess due to the extremely low levels present in bleached kraft mill effluents.

Recently Lindström–Seppä and Oikari (1989) published results from experiments where half of the rainbow trough from two groups were injected with TCDD at a dose of 2 µg TCDD/kg. The injected and control groups were further divided so that half of the fishes were exposed to untreated BKME and the other half to clean water. The results showed extremely high induction of liver and kidney detoxification enzymes caused by TCDD alone and together with BKME. BKME alone did not induce the enzymes above control values. It can be concluded that TCDD levels present in the BKME did not induce detoxification enzymes, at least during the experimental premises used.

The proposed ALPAC mill will mainly produce hardwood pulp from aspen poplar. In general, little is known about the effects of hardwood bleaching, as compared with softwood bleaching. Bengtsson et. al. (1988) studied the effects on vertebral characteristics in fish exposed to effluents from, unbleached and bleached hardwood production. In this study, and the studies performed by Oikari et al. (1984) with simulated kraft mill effluents, effects were obtained at equally high effluent concentration levels, using untreated effluent from the unbleached pulp and bleached hardwood production. Differences between the compositions of effluents from mills using birch and aspen (as in the case of the ALPAC) are at present poorly known. However, the ALPAC mill effluent will undergo secondary treatment in an activated sludge plant. BOD will be reduced 70 to 90 %, COD 40 to 50 % and AOX 40 to 50 of the original values.

Corresponding values for the mill effluents tested in the model ecosystem discussed above, which did not induce toxic effects, were the following:

Bleaching sequence	Effluent treatment	Wash.loss	BOD	COD	AOX
			–	kg/ADt	–
O84+D16 EDED	Aeration	6.3	2.2	29	1.8
O(C52+D48) EDED	No treatment	5.4	9.1	59	2.0

The concentrations of chlorinated phenolic substances were roughly 400–500 µg/L.

It is evident that the amount of chlorinated phenolic substances from the ALPAC mill will be very low after secondary treatment. The total content of chlorinated phenolic substances from other mills using activated sludge treatment were reduced by more than 50 %. The very high use of chlorine dioxide, will furthermore, considerably reduce formation of tri- and tetrachloroisomers in favor of mono- and dichloroisomers, which are easily degradable.

In October 1989 fish taken in Wapiti River, downstream near Procter & Gamble, and in the Athabasca River downstream near Weldwood have been sampled for PCDD and PCDF analyses. Results from these studies will increase the knowledge of presence of polychlorinated dibenzodioxins and dibenzofurans in these rivers. The results which were available are presented in Figures 7/18 and 7/19 and discussed below in item 7.3.7. The concentrations further downstreams from the mills and also upstreams without pulp mill loading are still, however, unknown.

7.3.3
Fish Tainting

While tainting of fish flesh cannot be considered toxic, either to the fish or its consumer (Thomas 1973), it may render a fishery resource useless for commercial and recreational purposes. Based on the information from fish tainting studies, some differences exist in the degree of fish tainting originating from pulp mills (Kovacs 1985). Water quality studies from the Athabasca River have shown that the water has a "pulp mill-like" odor and a possibility exists for fish tainting as far as 900 km downstream from the Weldwood pulp mill at Hinton (Noton et al. 1989). This suggests that effluents from the ALPAC pulp mill may also contribute to fish tainting during low flow conditions in the winter. There are, however, no studies of fish tainting in the Athabasca River close to the existing mills or near the proposed ALPAC mill site.

Recently acquired knowledge indicates that fish tainting is not considered a problem for effluents of pulp mills with biological treatment (McLeay 1986). According to Kovacs (1985) in the case of rainbow trout flesh, the tainting threshold of untreated BKME and BKME treated in an aerated lagoon was found to be 0.2 to 0.8 % and 2 to 2.9 % respectively. The effluent concentrations from the ALPAC pulp mill will be below these threshold levels. Chlorinated anisols and veratrols have been shown to cause fish tainting water for concentrations of 20 to 40 ng/g fish filet (Paasivirta 1988). These fish were caught about 10 km downstream from a pulp mill with activated sludge effluent treatment.

Secondary treatment of BKME reduces tainting by factors of two to ten (Sprague and Colodey 1989). This was also found in studies where rainbow trout were caged in receiving waters before and after upgrading of an old sulphate mill to more current technology. The upgraded mill was equipped with secondary treatment (Langi 1987). During the operation of the old mill there was a remarkable tainting within 30 km downstream, as compared to upstream conditions. After the mill renewal hardly any differences in fish tainting could be detected between upstream and downstream caged fish.

Caged rainbow trout have not been found to suffer any tainting in receiving waters with concentrations of chlorinated phenols of 40 to 77 ng/l (Tana and Lehtinen 1989) within 20 to 70 km downstream of pulp mills. As the concentrations of organic chlorinated substances in the Athabasca River downstream of the future ALPAC pulp mill site are not known it is difficult to estimate the possible contribution of its effluents on fish tainting. Tainting cannot be considered a problem in the Athabasca Delta and or the Slave River as a consequence of the effluents from the future ALPAC pulp mill.

7.3.4
Benthic Fauna

As a group, benthic invertebrates are an important component of flowing-water ecosystems (Hynes 1970). They occupy several positions in the aquatic food web, from detritivores to carnivores (Merritt and Cummins 1978), and are major food items for many species of fish. They include a diverse assortment of taxonomic groups which range from coelenterates to the more advanced insects, and they may be present on river beds in considerable abundance.

An overview of the literature on the toxicity of pulp and paper mill effluents made for the Environmental Protection Services, Environment Canada (McLeay and Associates 1987) concludes that pulp mill effluents which receive both primary and secondary treatment seldom have a toxic effect on aquatic invertebrate communities. Pulp mill effluents which receive only primary or no treatment at all usually have a detrimental effect on aquatic invertebrate communities. In the case of exposure to primary or untreated effluent, species diversity can be reduced and pollution tolerant taxa may become numerically dominant.

Three benthic invertebrate surveys have been conducted in the Athabasca River to investigate the effects of the effluents from Hinton pulp mill on the zoobenthos of the Athabasca River (Anderson 1989). The results obtained in the immediate vicinity of the effluent outfall suggest that mild nutrient enrichment gives rise to larger populations of all invertebrate taxa in shallow waters. It was also concluded that there is a shift in the invertebrate community composition to where tolerant taxa increase in numbers and intolerant taxa decline in numbers and diversity. This effect persists over a 20–50 km stretch of the river. The real cause of this effect remains undefined. Further benthic invertebrate work is required to determine the cause of the dominance of tolerant taxa and the extent of this dominance downstream. In 1980, following low river flows and water quality impacts at the town of Peace River, benthic monitoring by Alberta Environment indicated that the pulp mill effluent was causing a noticeable reduction in numbers of zoobenthos in the Wapiti River. It appears that the impact has lessened since 1980 (Noton et al. 1989).

The benthic fauna can be assumed to be similar in the vicinity of the proposed ALPAC effluent outfall as below the Hinton pulp mill and the same kind of mild enrichment of benthic invertebrates may be expected as in the vicinity of Hinton. Even where an adequately-treated bleached kraft mill effluent does not have measurable effects on aquatic invertebrate population densities or on community composition, sublethal effects have been reported. Petersen and Petersen (1984) observed that BKME and 4,5,6-trichloroguaiacol induced physiological damage in caddish fly (Hydropsychidae) larvae. Sublethal responses should be detected, but they are usually not reported in routine surveys. According to Anderson (1989) no information is presently available for the Athabasca River regarding the occurrence of chronic toxicity in invertebrate populations or in higher aquatic organisms including fish.

7.3.5 Eutrophication

Eutrophication is defined as the increased growth rates of biota of surface waters. The basic measurable criterion of accelerated productivity is increasing rates of photosynthesis by algae and larger plants per given area on an annual basis (Wetzel 1983). The biomass of planktonic and epilithic algae in water is often estimated indirectly from the amount of photosynthetic pigments, usually chlorophyll a.

The major macronutrients controlling the biomass production are phosphorus and nitrogen of which phosphorus is most commonly the first limiting nutrient in lakes (Wetzel 1983).

The effect of nutrient input to algal growth in an aquatic system is controlled not only by the amount and concentration of nutrients but also by their bioavailability, kinetics and interactions between nutrients sediment and water. Numerous studies have been conducted on the bioavailability of different phosphorus forms, but the knowledge of the role of different phosphorus fractions is still far from complete. Phosphate-P (measured as soluble reactive phosphorus) is known to be readily bioavailable. Only a portion of particulate phosphorus and soluble unreactive phosphorus is available for algal growth and this amount is highly variable depending on the form of the particulate phosphorus (Butkus et al. 1988). Inorganic soluble nitrogen (nitrate, nitrite and ammonium) is readily bioavailable, but soluble organic nitrogen is also able to maintain algal growth (Wetzel 1983).

The portion of total dissolved phosphorus to total phosphorus in Athabasca River water is roughly estimated to be around 10 % during the open water season and 50 % during winter months. Corresponding portions of dissolved inorganic nitrogen the total nitrogen are less than 10 % for open water and around 20 to 30 % during winter ice cover, based on the data in reports of Hamilton et al. 1985, Noton and Shaw 1989 and Alberta Environment 1990). These estimates indicate that the portions of readily bioavailable nutrients during the growing season are fairly low in spite of the high concentrations of total phosphorus and nitrogen.

The bioavailability of phosphorus and nitrogen in activated sludge treated kraft pulp mill effluent, similar to ALPAC effluent, is not well known. The results from the Finnish activated sludge treated kraft pulp mill effluents studies indicate that the ratio of total phosphorus to total dissolved phosphorus vary to some extent depending on the process and effluent treatment conditions, wood species etc. Less than 50 % of phosphorus seems to be in particulate form (Järvinen 1990). Part of the particulate phosphorus may also be easily degradable and release bioavailable phosphorus.

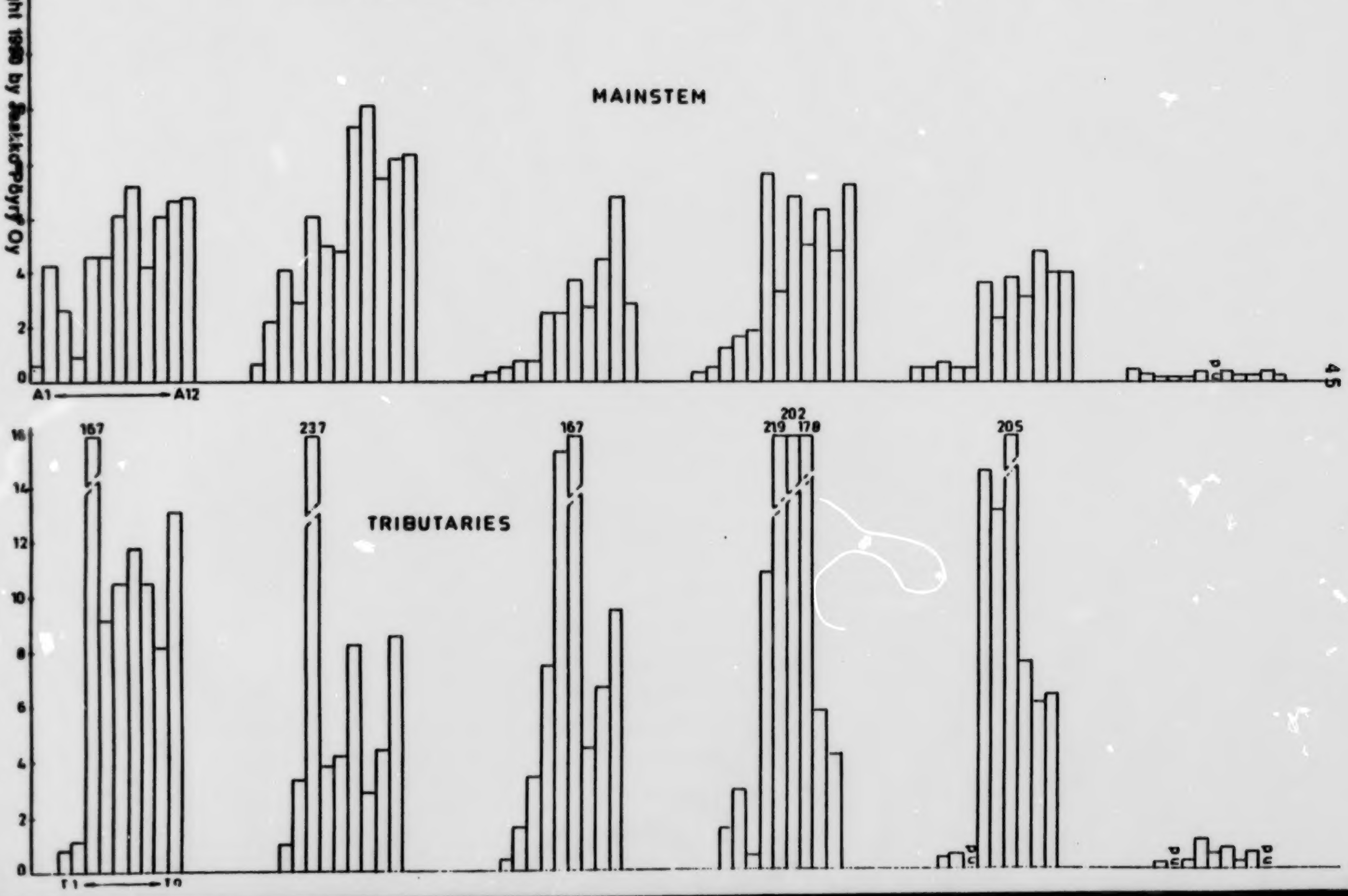
According to the phytoplankton chlorophyll a measurements in Hamilton et al. (1985), the growing season in the Athabasca River is from May to October. The chlorophyll a values show a longitudinal increase downstream in the mainstem of the river. The chlorophyll a concentrations do not follow the high seasonal changes in total phosphorus, but are moderately low in general (Figure 7/15) indicating that most of the particulate phosphorus fraction, that flush into the river during high flow season, is unavailable for algae production.

The ALPAC effluent's contribution to phosphorous concentration in the river water at Athabasca is estimated to be less than 1 % of total phosphorus and less than 5 % of dissolved phosphorus in June and July, and roughly around 5 % and 15 % in May and October, respectively.

As discussed in section 7.1 the ratio of phosphorus and nitrogen in the pulp mill effluents is likely to be close to the optimal for algal growth. However, the calculated contribution of phosphorus and nitrogen from the pulp mill effluent to the river water is likely to be insignificant for the algal growth during the summer months. The possible impacts on algal growth, if any, would occur in May and from September to October when the river flows and background concentrations of nutrients are fairly low.

The previous discussion considers only the role of phosphorus and nitrogen and their concentrations in algal growth. Other factors, of which probably the most important are the sedimentation dynamics, phosphorus kinetics and turnover time and light penetration, are not discussed because of the lack of baseline data on the Athabasca River. These factors, in addition to the input amount and form of phosphorus, are controlling the eutrophication of Lake Athabasca as well. It is probable that particulate phosphorus is fairly strongly bound to inorganic suspended solids. No baseline data from Lake Athabasca has been available, but due to the flow conditions and the basin characteristics of South–Western part of the lake, no large-scale release of dissolved phosphorus is expected from the bottom sediments. However, monitoring of the nutrient dynamics and algal growth in Lake Athabasca is necessary to confirm the previous assumptions.

FIGURE 7/15
Seasonal Phytoplankton Chlorophyll a Distribution
for Athabasca Mainstem and Tributary Sites, 1984/85
(from: Hamilton et al. 1985)



7.3.6
Ecotoxicological Effects

Introduction

One of the most important tasks of the Complementary Review was to provide additional scientific information on the possible ecotoxicological impacts of the ALPAC project. According to Tuomisto (1990) in the risk assessment one should always make clear distinction between the facts and the hypotheses. The highly toxic effects of 2,3,7,8-TCDD on the Guinea pig and Sprague-Dawley rat is a fact but high toxicity on human beings is a hypothesis.

The potential deleterious environmental impact of chlorinated organics, particularly the dioxins and furans formed in the bleaching process, was discussed in the March, 1990 Report of the EIA Review Board. The toxic effects of several individual compounds in pulp mill effluents is well documentated. However, the synergistic and anthagonistic effects and the contribution of the identified toxic compounds on the effluent overall toxicity is less well understood.

Studies based on the chemical characterisation and acute toxicity measurements of untreated combined bleached kraft mill effluent (BKME), process streams and effluent fractions illustrate the impacts of different combinations of effluent constituents on acute toxicity (Priha and Talka 1986, Priha and Talka 1988). The following description is based on these studies.

Figure 7/16 illustrates the mass balances of some effluent constituents and water flea (Daphnia) toxicity in BKME process streams and the combined whole mill effluent from these process streams. The mixed effluent is marked with a line at 100 %. The contribution of resin and fatty acids from the evaporation stage (4) is missing from the mass balance. The toxicity balance (as Toxicity Emission Rate) clearly shows the the summarised toxicity of the process streams is over three fold higher than the combined effluent toxicity. Figure 7/17 illustrates a further increase in toxicity when the combined effluent is fractionated by membrane filtration based on molecular size distribution into three different effluent fractions. It can be concluded that not only the concentrations of individual effluent compounds, but also their combination with other effluent constituents determines the final toxicity. It is likely, although not known, that the sublethal toxicity would follow the same pattern. No studies are available on estimating whether or not the toxicity behaves in the same manner in the receiving waters as it behaved in the artificial fractionation.

FIGURE 7/16
Material Balances of BKME Process Balances
Compared to the Combined Mill Effluent (= 100)
(Priha and Talka, 1986)

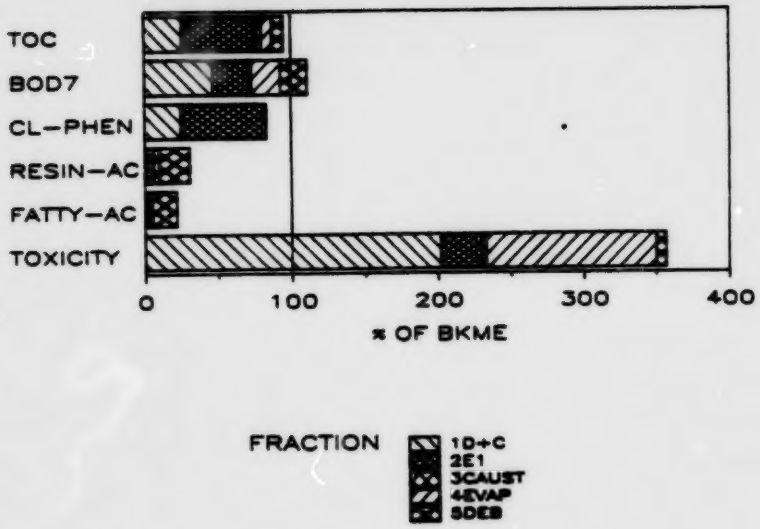
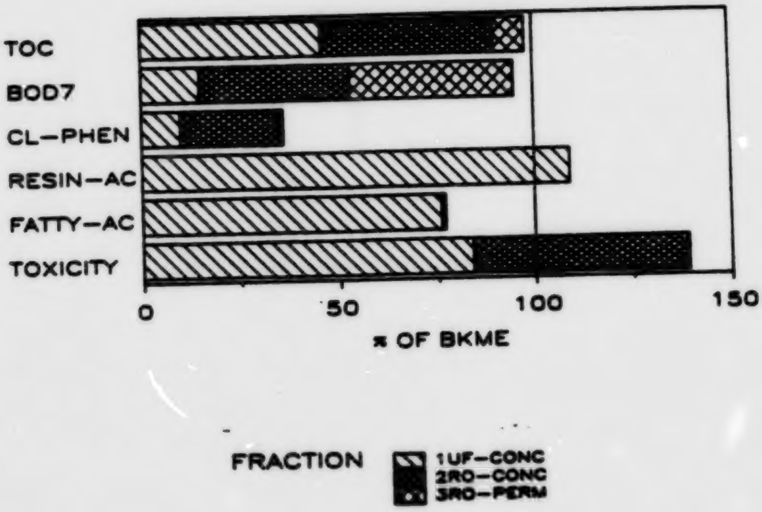


FIGURE 7/17
The Material Balances of BKME Membrane Fractions
Compared to the Combined Mill Effluent (= 100)
(Priha and Talka, 1986).



The most toxic of the dioxins, 2,3,7,8-TCDD is extremely dangerous to most living organisms, causing significant toxic impacts at exceedingly low doses. The same is true for the furan of greatest toxicological concern; 2,3,7,8-TCDF. This substance generally considered to be about on-tenth (0.1) as toxic, but is found in concentrations roughly ten times higher.

It is interesting that the paper which reported the highest toxicity found in the scientific literature relating to 2,3,7,8-TCDD and 2,3,7,8-TCDF in very small (<0.5 g) rainbow trout fry (Mehrle et al. 1988) indicated that 2,3,7,8-TCDF was less than 0.021 the toxicity of 2,3,7,8-TCDD - some five times lower than the accepted toxic equivalent for 2,3,7,8-TCDF. The paper by Mehrle et al. (1988), which found that 2,3,7,8-TCDD water concentrations as low as 38 pg/l (ppq) caused significant delayed mortality of trout fry after 28 days of continuous exposure, was extremely important to many of the arguments put forward against the ALPAC project, and is thus worth examining in some detail.

A careful evaluation of the scientific methods used in this paper, however, revealed some very serious flaws that should be considered in light of the importance of the results. The most significant error in this work was the absence of a solvent (carrier) control for both the 2,3,7,8-TCDD and 2,3,7,8-TCDF experiments.

There were other problems with this paper as well. One involved the measurement of wet weight as the only measurement of "growth". Given that appetite suppression was reported as an observation in all exposures (however, the amount of food consumed was not regulated or measured), any changes in net weight between exposed and control fish could be due to reduced food consumption and not to fundamental changes in the physiological processes that govern growth.

A final criticism of this paper is that although total length was reported to have been measured in the method, there were no reports of these results, nor any discussion of why the length measurements had been omitted. As a consequence of these flaws in experimental design and procedures, the results of this paper have to be regarded as questionable, and must be treated with caution.

Present TCDD/TCDF Concentrations in the Delta of the Athabasca River and Slave River System

The reported dioxin/furan results for fish from the Slave River of the Northwest Territories near Fort Smith (Whittle, 1989-Document # H-2) showed no detectable TCDD in whole longnose suckers (detection limit of 2 ppt) and no detectable TCDF in four of five suckers (detection limit 1 ppt), with one sucker containing 2 ppt of 2,3,7,8-TCDF. Another report on the same fish indicated no significant induction of liver microsomal enzyme activity (a very sensitive bioindicator of organochlorine exposure) nor proximate composition effects (Lockhart et al, 1989– Document # H–1). It can thus be concluded that there is no evidence of deleterious effects or bioaccumulation of TCDD/TCDF in fish from the Slave River, as a consequence of more than thirty years of kraft mill operation and effluent release into the Athabasca and Peace River System.

In addition there was no evidence of 2,3,7,8–TCDD or 2,3,7,8–TCDF contamination from a sediment study done for the lakes in the Athabasca and Birch River deltas (Egg, Sucker and George (control) lakes). There was some questionable evidence of natural dioxins in the control lake sediments, possibly as a consequence of previous forest fire activity in the region. This would indicate that there has been no significant effect on the delta lakes ecosystem from the dioxins/furans released into the Athabasca River up to the present time (Document # O–96). This result is very important because the Weldwood kraft mill has been releasing high levels of AOX into the Athabasca River for over 30 years. Previous effluents were likely much higher in dioxin/furan content than in recent years because of the old technology employed in the past, and the lack of knowledge concerning the potential source and production of these toxic compounds.

Potential Ecotoxicological Impacts of the TCDD and TCDF

The albeit limited scientific evidence available gives no indication that the delta area has been significantly affected by past effluent discharges from over 30 years of pulp mills operation in some cases for over thirty years. Hence, the area of possible effects of ALPAC would appear to be limited to the regions of the Athabasca River between the ALPAC mill site and Grand Rapids. Most scientific evidence presently available indicates it is very unlikely there will be any other significant toxicological effects of the ALPAC mill effluent on the Athabasca aquatic ecosystem provided the concentration of the biotreated effluent is kept below 5 % and the mill is efficiently and properly run (Bonsor et al. 1988; Sprague and Colodey. 1989 – Document # C–5; SPPEAE, 1989 – Document # A–22).

Using the food chain accumulation model results presented to the EIA Review Board by Derek Muir (Document # L–30), it was predicted that approximately 5 ppt of TCDD and TCDF (ng/kg wet wt) would be accumulated in whole fish in the immediate receiving waters near the ALPAC mill (the mixing zone). This would seem to be a more accurate estimate of the potential bioaccumulation than the estimates provided by the ALPAC model, given ability of Muir's model to predict current concentrations of TCDD/TCDF in the fish downstream of the present operating mills. This same conclusion was reached by the EIA Review

Board as well. Given that 25–30 % of the dioxins/furans in whole fish will be present in the edible flesh (Bonsor et al. 1988), this gives 1.25–1.5 ppt of both 2,3,7,8–TCDD and 2,3,7,8–TCDF in the fish flesh. Taking these values together, a toxicity equivalent (TEQ) for [TCDD + TCDF] of 1.65 ppt in the flesh of the fish found immediately downstream of ALPAC (i.e. the "worst" case scenario for fish exposure at this exposure level) is determined, which is 8.25 % of the national limit of 20 ppt TEQ for fish consumption.

It is anticipated that the downstream environment is properly monitored for any unpredicted deleterious effects on the aquatic ecosystems including any contamination of aquatic organisms. ALPAC has committed itself to upgrade the present state–of–the–art technology to even higher levels of environmental acceptability.

With the proposed technology the annual loading of dioxins and furans is maximum 0.9 g based on a 30 ppq practical detection limit for dioxin/furan and a non–detectable effluents as calculated by Alberta Environment (1990a). Provided that the proposed safe–guards, monitoring regimes, and environmental regulations are adhered to, there should be neither short term or long term irreversible damage to the Athabasca River downstream from the proposed ALPAC mill.

7.3.7
Human Health Effects

Identification of Risk Groups

The population of the region is relatively low in relation to the land area concerned. Major population centres down stream from Athabasca include the Fort McMurray area, where the Fort McMurray district health unit is concerned with the health issues of approximately 37,500 people, Further down the waterway, beyond the Slave River in the northwest territories, there are approximately 37,000 people who could be effected by industrial developments on the Athabasca River. The large land and low population involved will have a significant bearing on the likely impact of the ALPAC development downstream from Athabasca. Contaminants which may be carried down the river and accumulated in the food chain are likely to represent the only significant impact on human health. Any risk assessment has to be made on the basis of current knowledge or the contaminant production by the pulp and paper industry.

The available data on TCDD (or PCDD) and TCDF (or PCDF) contamination in Alberta and the Northwestern Territory is so scarce that it is very difficult to identify risk groups. However, it can be expected from experience elsewhere that in this essentially non–urban region there are two risk groups that are likely to be affected by PCDDs and PCDFs. These would be the heavy consumers of milk and the heavy consumers of fish. No information has been presented on the concentration of these contaminants on either breast milk or cow's milk in Alberta. Consequently, it is impossible to make any predictions on risks associated with heavy milk consumption. On the other hand, it is possible to assess the milk consumption of the native populations and make some comparisons with existing literature data. A very limited amount of data is available on the concentration of these compounds in fish.

In the paper, "Baseline Contaminant Levels in Selected Slave River Fish Species" indicate that the level of total dibenzodioxins and dibenzofurans are below detection limit or very low in burbot livers or longnosed suckers (Figure 7/18). These were measured in whole fish. However, the sample numbers are small and collection points are relatively far from the proposed ALPAC plant. Nevertheless, these figures provide some comparison and potential baseline for the future monitoring.

The highest concentrations of dibenzodioxins and dibenzofurans were emitted immediately below the Procter & Gamble (Figure 7/19) plant and the Weldwood plant (Figure 7/20) on the Athabasca River. For 2,3,7,8–TCDD these concentrations were 5–17 ppt and 3–17 ppt, respectively. Correspondingly, the 2,3,7,8–TCDF concentrations ranged from 18–290 ppt and 16–1 ppt. Clearly, more samples are needed for baseline determinations. However, these values will permit a preliminary estimate of potential intake of TCDD and TCDF.

FIGURE 7/18
TCDD and TCDF Concentrations in
Fish Samples from the Slave River

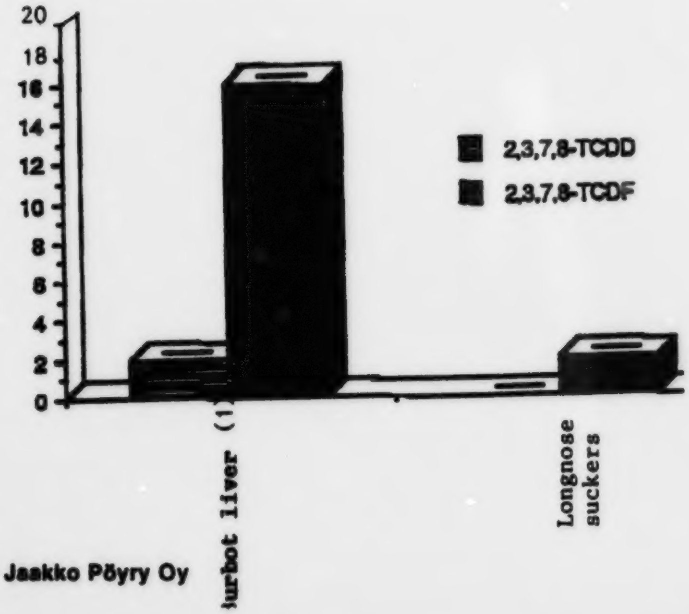


FIGURE 7/19

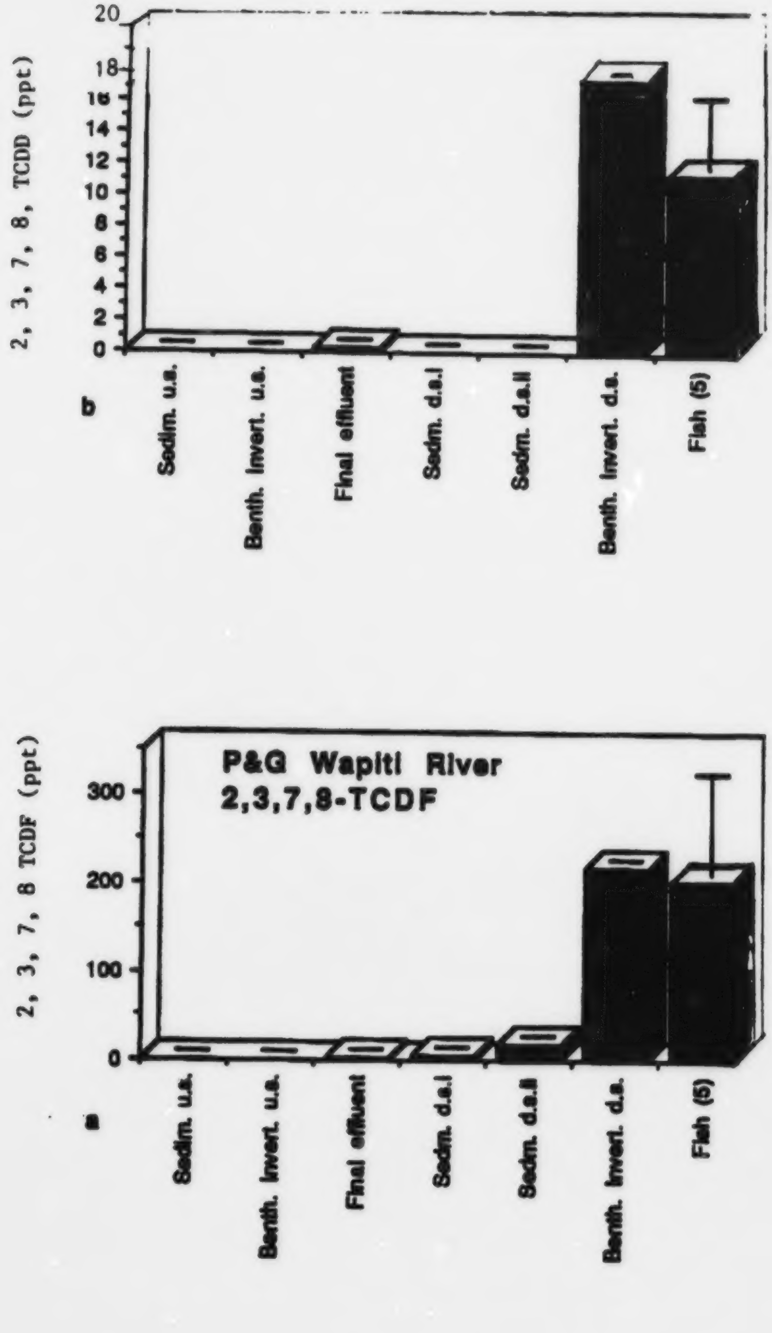
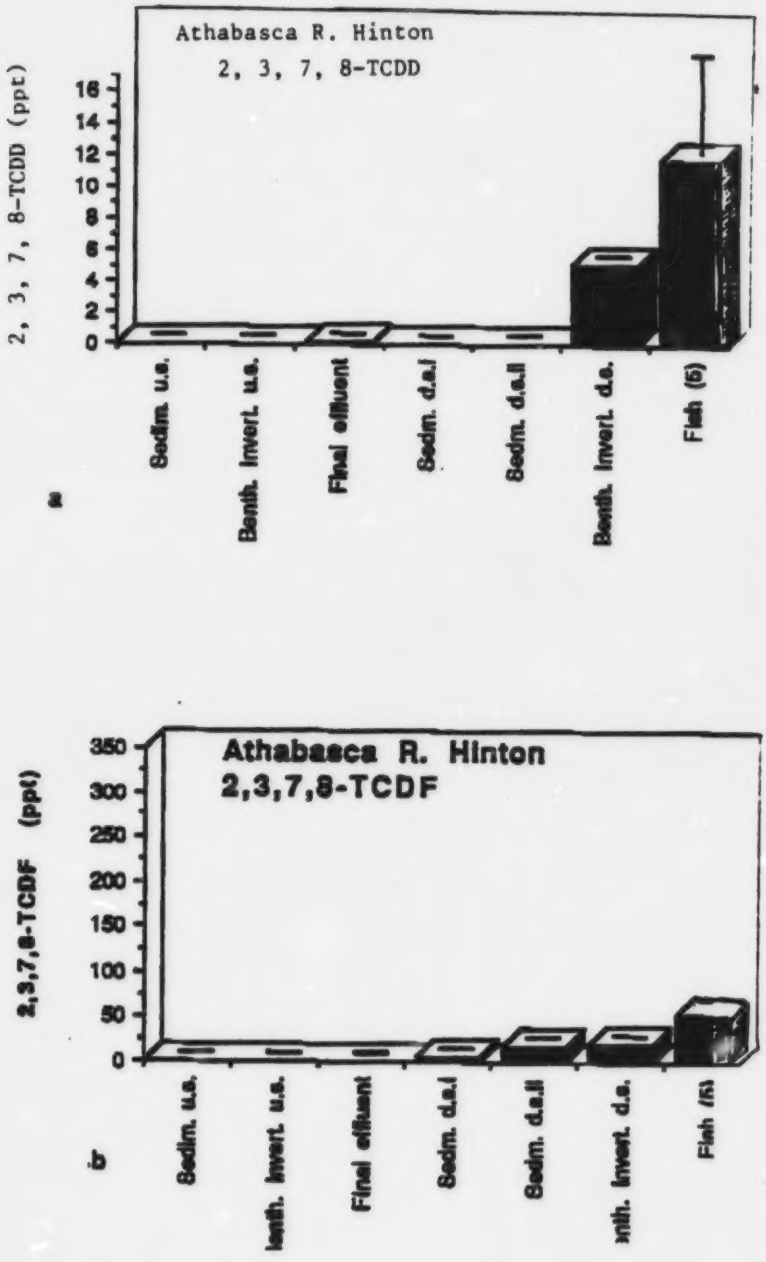

2, 3, 7, 8, TCDD (ppt)
20
18
16
14
12
10
8
6
4
2
0
b
Sedim. u.s.
Benth. Invert. u.s.
Final effluent
Sedm. d.s.I
Sedm. d.s.II
Benth. Invert. d.s.
Fish (5)
P&G Wapiti River
2,3,7,8-TCDF
2, 3, 7, 8 TCDF (ppt)
300
200
100
0
a
Sedim. u.s.
Benth. Invert. u.s.
Final effluent
Sedm. d.s.I
Sedm. d.s.II
Benth. Invert. d.s.
Fish (5)

FIGURE 7/20


Athabasca R. Hinton
2, 3, 7, 8-TCDD
2, 3, 7, 8-TCDD (ppt)
0
2
4
6
8
10
12
14
16
Sedim. u.s.
Benth. Invert. u.s.
Final effluent
Sedm. d.s.I
Sedm. d.s.II
Benth. Invert. d.s.
Fish (5)
a
Athabasca R. Hinton
2,3,7,8-TCDF
2,3,7,8-TCDF (ppt)
0
50
100
150
200
250
300
350
Sedim. u.s.
lenth. Invert. u.s.
Final effluent
Sedm. d.s.I
Sedm. d.s.II
›nth. Invert. d.s.
Fish (5
b

Native Albertan Country Food Fish Consumption

An issue that has been given a great deal of prominence in the hearings, is the fact that the native population of Northern Alberta and the Northwest Territory use fish as a major part of their diet. Consequently, from experience in other parts of the world, they would appear as a group most at risk.

A lot of anecdotal information was presented to the review panel relating to the dietary habits of the aboriginal people of the region. However, a very important document did not get presented to the hearings, namely the PhD thesis of Eleanor Wein. This extensive study of the use of country foods by the Northern Aboriginal people is extremely valuable providing a description of both the quantity and quality of fish consumed by native peoples living in Fort Smith, NWT, and Fort Chipewayan, Alberta., The title of the thesis is "Nutrient Intakes and Use of Country Foods by Native Canadians near Wood Buffalo National Park" presented to the Faculty of Graduate Studies of the University of Guelph. The author has collected information on the dietary habits of the population of this region by using dietary recalls as a method of accumulating the data. The attached tables summarise the some of the key issues (Appendix V).

In this study, people were divided into 3 main age groups (shown below) and fish consumption patterns differed with grouping.

Adolescents & Young Adults = 13-24 years of age
Middle Adults = 25-49 years of age
Older Adults = 50-86 years of age

The largest fish consumers were the older adult males who consumed 36 g of fish per day at a frequency of 0.2 times/day.

The adolescents and young adults plus middle adults (ages 13-49) represent a group that will be most at risk due to any future pollution. Their fish flesh consumption pattern is shown below:

TABLE 7/9
Fish Consumption by Adolescents and
Young Adults Plus Middle Aged Adults

Species	Total Eaten (muscle tissue only)	Amount Eaten (g/week)
Whitefish	51.5 %	13.3
Pickeral	14.5 %	3.5
Pike	14.5 %	3.5
Lake Trout	9.7 %	2.8
Goldeye	3.2 %	0.7
Sucker	3.2 %	0.7
Others (Loch, fish eggs, inconnu	3.3 %	1.4
Total	100 %	25.9

Note: The top six fin fish make up 96.7 % of total fish consumption, burbot are not listed, and no mention is made of fish organ consumption (such as burbot liver) in this study, even though all sources of food intake were studied including organ consumption from caribou, moose, bison, bear and goose. This is relevant as concerns have been expressed that the native population would have a high intake of contaminants accumulated in the liver of burbot.

Dr Wein's thesis gives the consumption figures for 'country foods' giving the total frequency as 0.6 times per day, i.e. every other day some country foods are included in the diet. That means that there are significant amounts of processed foods in the Indian diet and they contribute significantly to the overall intake assessment. Even taking into account the total fish consumption (from other sources) as well as the fish from the local sources, i.e. country food fish the local Indians appear not to be eating fish in larger amounts than other Canadians. The intake of fish for the "average" Canadian is given as 98 g/week.

It may be of importance to note the difference between young adults, middle adults and older adults. There are great variations in fish consumption (from 7 to 36 g/day with 0.05–0.2 times per day). This is reflected also in the beliefs study where older people appear to think of fresh fish as one of the healthier staple foods in their diet. Simultaneously, the young appear to rely on modern ideas of fruits and vegetables and this is also reflected in their choices and intakes. We should keep in mind that although the young are by far the most important group in terms of exposure, all possible special groups and exposure levels must be taken into account. Therefore, the calculations have been performed to represent all age groups. It would be preferable to take into account the upper 10th percentile instead of the upper 20 %. However, this has not been possible from the presented data.

Intake estimates may be made in various ways.

1. When a contaminant is known to be in the food but cannot be detected by analysis, the maximum contaminant concentration is assumed to be equal to the lower detection limit. These values are then used as the basis for calculations, i.e. using in this case the highest observed dioxin or furan concentrations as the basis for intake estimates.
2. Another extreme would be to multiply the highest found concentration with the highest amount of food item consumed to provide a high intake estimate, i.e. here taking highest concentrations of dioxins and highest fish consumption figures from older adults together and maybe even maximizing it to the upper 10 or 20 % consumers.
3. The only accurate way is to conduct duplicate meal (portion) studies by analyzing samples from populations at risk, i.e. native Indians in the Athabasca area.

As far as dietary recalls are considered as nutritional intake study methods one has to remember that there are both random errors and systematic errors often included in the result. It has been estimated that coding errors range from 3–27 %, estimated food weights have an error range of 20–50 % and reporting errors have been observed ranging from 4–400 % in the 24 hour dietary recall method. And these include just a few possibilities which means that dietary recalls need to be conducted by trained and experienced interviewers as well as careful initial planning and training of all other workers involved. From the material available it is not possible to assess all the likely sources of error. The local native subjects may have been difficult for a student interview, thus altering the results in an unexpected way. The figures require extremely careful interpretation; estimates should tend to overestimate any possible extremes and also indicate variation between different dietary subgroups. Consequently we have made comparisons with the Nordic fish consumption which is very much higher than the high Canadian fish consumption.

Examples of weekly TCDD intakes for normal and extreme consumers of fish in Nordic countries and Alberta are presented in tables 7/10 and 7/11. Intake of TCDD is in pg/kg body weight (in parentheses % of Tolerable Weekly Intake[1]). All consumptions are based on 70 kg persons.

TABLE 7/10
TCDD Intake Associated with Nordic Fish Consumption

Fish	TCDD content (pg/g muscle)	Normal consumer (210 g/week)	High consumer 840 g/week
Cultivated Salmon	0.25	0.75 (2.1 %)[1]	3.0 (8.6 %)[1]
Baltic Sea Salmon	4.6	13.8 (39.4 %)	55.2 (159.2 %)
Cod	0.8	2.4 (6.9 %)	9.6 (27.4 %)

TABLE 7/11
Estimated TCDD Intake Based on Fish from Alberta/NWT When Consumed According to the Nordic Consumption Patterns

Fish	TCDD content (pg/g muscle)	Normal consumer (210 g/week)	High consumer 840 g/week
Burbot (liver) (Slave River)	2	6 (17.1 %)[1]	24 (68.6 %)[1]
Longnose sucker (Athabasca River d/s Hinton)	9	27 (77.2 %)	108 (308.6 %)

[1] Tolerable Weekly Intake (TWI = 0-35 pg TCDD/kg of body weight/week) Nordic recommendation 1988). Figures parenthesis refer to percentage prints of Tolerable Weekly Intake.

[2] Wein 1989

TABLE 7/12
Estimated TCDD intake based on fish from Alberta/NWT when consumed according to the local fish consumption patterns based on best available data[2]. Fish consumption is expressed in g/week.

Fish	TCDD content (pg/g fish)	Normal consumer (98 g)	Upper 20 %** (245 g)	High* 252 g)	Upper 20 % high*** (630 g)
Burbot (liver) (Slave River)	2	2.8 (8.0 %)	7.2 (20.6 %)[1]	7.0 (20.0 %)[1]	18.0 (52.4 %)[1]
Longnouse sucker d.s. Hinton	9	12.6 (36.0 %)	32.4 (92.5 %)	31.5 (90.0 %)	81.0 (23.1 %)

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[1] Tolerable Weekly Intake (TWI = 0–35 pg TCDD/kg of body weight/week) Nordic recommendation 1988). Figures parenthesis refer to percentage prints of Tolerable Weekly Intake.

[2] Wein 1989

*Older males; ** 2.5 times higher than the entire sample; ***2.5 times higher than average old males' fish consumption
d.s. = down stream

Table 7/10 shows the current situation in Scandinavia. It is notable that the normal Nordic fish consumption is very much higher than the Canadian average or the fish consumption observed in the Athabasca/Slave River region. It is notable that even the high Nordic consumers would not exceed the TWI for TCDD if their fish consumption consisted only burbot liver from the Slave River.

It would appear extremely unlikely that TCDD TWI's would be exceeded by the general population eating fish from mixed sources. There is not adequate data available for Alberta to asses the overall dibenzodioxin and dibenzofuran intakes in terms of TCDD toxic equivalents (TEQ). Even if somehow all fish consumed contained 20 ppt of TEQ in their flesh which is the Ontario maximum consumption limit, the level of local fish consumption would only result in the intake of 10 % of the TEQ allowed by the Ontario ADI (allowable daily intake) of 0.01 ng/kg/d. There is no evidence that would suggest exposures exceeding these levels down stream of Athabasca.

Thus in conclusion, the native peoples of the Lake Athabasca area (Fort Chipewyan) and of the Wood Buffalo National Park area (Fort Smith) have present day fish consumption patterns which are significantly lower than the average Canadians (roughly one quarter) and that as a result they are very unlikely to be at risk of exceeding allowable intakes of chemicals such as dioxine as a result of fish consumption, irrespective of whether or not the ALPAC project is allowed to proceed.

Effects on the Drinking Water Quality in Alberta

The pulp mills in Alberta are not located immediately above water intake points for any drinking water supply. However, it has been a concern that the drinking water supply in Fort McMurray which is located along the lower part of Athabasca River, could be adversely affected. The Canadian Water Quality Guidelines stipulate for maximum acceptable concentration for many different parameters in the raw water. The results of this project indicate that there is no risk of exceeding the maximum acceptable limits for any Canadian Water Quality parameter at Fort McMurray due to pulp mill effluents.

8
ENVIRONMENTAL MONITORING

8.1
Scope of Environmental Monitoring

As mentioned in numerous places in this review, on-going and continuous monitoring of the Athabasca-Peace River system is an extremely important aspect of environmental management if the ALPAC mill project is to proceed. It is only possible to evaluate the effects of ALPAC pulp mill effluent if good data are available before and after mill start-up. Continuous monitoring is necessary to ensure that no unexpected environmental damage is occurring or has occurred.

In order for the specific monitoring program to determine the effects of the ALPAC mill on the Athabasca River itself and on the whole Athabasca-Peace River watershed, the monitoring program must be comprehensive and integrated into an overall Athabasca-Peace River system monitoring effort. It is particularly important to ensure that adequate long term funding is available to support the larger scale monitoring programs. This requires some type of overall coordination to prevent wasteful and inefficient use of the financial resources that are committed to the program.

One of the recommendations made to the EIA Review Board (Ed Barnes of E.T. Barnes and Associates Inc.) with respect to monitoring of the Peace-Athabasca River system was the creation of a permanent Peace-Athabasca Waterways Commission to coordinate a program of acquatic monitoring that "is long term, extensive, well planned, well supervised, and well financed if the environmental needs are to be fully served". If the ALPAC mill is approved and the effects of it and other mills in combination are to be properly evaluated, then this or some other type of coordinated long term, large scale monitoring must be utilised.

In a report prepared for the Procter and Gamble Company (SPPEAE, 1989), by a distinguished group of scientific experts on pulping effluents in the aquatic environment, an integrated and tiered hazard assessment approach was recommended for estimating pulp mill impacts on aquatic ecosystems.

The critical questions to be addressed by the activities were defined in this report as follows:

1 "Are water or sediments in the receiving system contaminated with chemicals associated with the pulp mill effluent?

2 Are organisms associated with the receiving system exposed to these pulp mill chemicals?

3 Are the water and sediments in the receiving system toxic to the biota?

4 Have aquatic biological populations and communities associated with the receiving system been measurably impacted by pulp mill effluents?

5 Are the effects on biological communities and populations associated with the receiving system caused only by contaminants from the pulp mill effluent?"

By addressing each of these questions in the logical order that they are listed (hence a tiered approach to biological monitoring), it is possible to determine if any deleterious impact to the health of the receiving aquatic environment is occurring. The use of biomarkers such as liver enzyme induction to measure of immune suppression, histopathology etc. in a monitoring program is highly recommended to provide an indicator of both exposure and sublethal effects in the field. These can then be related to potential whole organism effects such as increased mortality, decreased growth or impaired reproduction in the laboratory. Because of linkages through the food chain, any of theses effects, such as decreased reproductive capacity of one species, can have a marked effect on the entire biological community.

8.2
ALPAC Monitoring Program

However, the need for coordination must not retard the monitoring activities to be initiated by ALPAC. Therefore, ALPAC have proposed a monitoring program to accomplish both baseline data collection and on-going river monitoring (ALPAC 1989d). This program, to be operated and run by Alberta-Pacific, is an important interim aspect of the ALPAC project.

The program is found to be a very reasonable one and quite comprehensive. However, the following amendments could enhance its overall utility and effectiveness:

1 At least five sites should be utilised for a water quality and sediment chemistry program for "In-River Monitoring". These would include:

   - a sampling site above the outfall
   - a sampling site immediately below the outfall within the mixing zone
   - a sampling site immediately outside of the defined mixing zone
   - a sampling site just above Grand Rapids, and
   - a sampling site just below Grand Rapids

2 A "sentinel" organism monitoring program needs to be incorporated into the main program at the same sampling sites as described above for the sediment chemistry program. This would involve use of a "sentinel" invertebrate filter-feeding organism such as freshwater mussels or clams. Crustacea may also be used if necessary but the stationary nature of the bivalves and their relative longevity makes them ideal. These should be collected for analysis of both metals and chemicals, including a full dioxin/furan scan in their tissues. These animals provide a full profile of chemicals that they have been exposed to. This allows measurement of the total bioavailability and bioconcentration of chemicals in the river system.

   The presence of a full spectrum of contaminants in "sentinel" invertebrates such as freshwater mussels also provides an identifiable pattern from which the source of the chemicals can be identified. Use of a caging protocol to transfer "clean" mussels into "contaminated" areas for known amounts of time and vice versa also allows for good estimates of uptake and depuration rates under natural exposure conditions. This type of "sentinel" organism monitoring should be done at the same initial frequency, say 4 times per year seasonally, and in association with sediment chemistry monitoring.

3 Baseline and on-going measurements should be undertaken to determine the background concentrations of metals and toxic chemicals in resident waterflow, particularly fish-eating birds. Consideration should be given to monitoring bird eggs for bioaccumulation of persistent chemicals (e.g. herring gull egg monitoring). This should be done annually.

8.3
Baseline Studies and Monitoring of Fish Populations

It has been recommended in the Review Board report that surveys of fish, their habitat, and food chains that support them should be conducted. The survey should include baseline and on–going studies for chlorinated organic compounds, dissolved oxygen in the river and taste and odour problems in water as well as fish tainting.

As has been concluded in previous chapters there is a lack of information concerning fish, fish habitat, fisheries and sublethal effects on fish as well as fish tainting. In order to make a more complete impact assessment on the impacts of the proposed ALPAC mill this information is definitely needed and a program should be put in place to obtain it.

These studies should be concentrated on areas downstream of the proposed ALPAC mill site and for sublethal effects should extend into in the areas downstream Grand Rapids and in tributaries. Studies are also needed in upstream parts of the river in order to get sufficient reference material from areas without pulp mill effluent loading.

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JAAKKO PÖYRY

Jaakko Pöyry Oy

(until 31.7.1991)
(Kaupintie 3) P.O.Box 16
SF-00441 HELSINKI, FINLAND
Tel.: Int. +358-0-5011, Fax: Int. +358-0-562 5743
Telex: 121069 jpcon sf

(1.8.1991 on)
(Martinkatu 3) P.O.Box 4
SF-01621 VANTAA, FINLAND

APPENDIX I
TERMS OF REFERENCE

SCHEDULE 'A'

PROJECT SERVICES

ARC CONTRACT NO.: JPO 100.00.91

Complementary Scientific Review of the Alberta-Pacific Pulp Mill Project to be carried out by JAAKKO POYRY OY.

TERMS OF REFERENCE

Conduct an independent scientific review and evaluation of the data related to the Alberta-Pacific Environmental Impact Assessment (EIA) Review with special emphasis regarding chlorinated organic compounds and predictive models of dioxin and furan concentrations at various levels in the aquatic food chain.

1. GENERAL

The objective of the study is to evaluate the earlier impact assessments of the proposed Alberta-Pacific Pulp Mill Project. In order to meet the scientific standards required for this kind of evaluation an expert group of consultants with a wide range of experience in environmental issues related to the pulp and paper industry has been assembled by JPO. This expert group will evaluate the final report of the EIA Review Board and the relevant baseline data submitted to the EIA Review Board. Earlier EIA studies and the scientific data will be supplemented on the issues considered necessary. Present emission standards and present loads from existing mills in the Athabasca and Peace River system will be considered as a background.

The study will focus on the following major areas:

- Pulp Mill Technology

- River Dynamics
- Fate of Contaminants
- Impacts on aquatic food chain

2. AREA COVERAGE

The study will cover the Athabasca River up- and downstream from the Alberta-Pacific Pulp Mill site as well as Lake Athabasca and Slave River. The contribution of the Peace River to water quality along the Slave River will be taken into account provided that adequate data are available.

3. MAJOR ISSUES

Major issues in the study are:

A. The Proposed Pulp Mill Development

A comprehensive evaluation of the mill processes, effluent treatment concepts, anticipated effluent load and air emissions of the mill will be carried out. Special attention will be paid to the formation of chlorinated organic contaminants such as chlorinated dioxins, furans and phenolic compounds.

B. Effects of the Mill Effluents on the Athabasca River and Water Course Downstream

The Athabasca River System will be reviewed from hydrological, ecological and toxicological points of view. This will include the following subsections:

i) Chlorinated Organic Compounds

Toxicity, bioaccumulation and persistence of chlorinated organic compounds will be reviewed. Their initial concentrations and distribution between water, sediment and aquatic food chain will be evaluated. The present and predicted future concentrations of chlorinated organic compounds in the river system will be calculated. Toxicological risk assessment will be carried out.

ii) Dissolved Oxygen (DO)

The effect that the biochemical oxygen demand from the effluent load will have on the dissolved oxygen concentration in the river system will be considered. This effect will be calculated at different flow conditions with appropriate water quality models. The effects of predicted DO concentration on the aquatic food chain will be evaluated. Variations in the seasonal conditions of the Athabasca River System will be taken into account. The possible synergistic effects between DO and chlorinated organic compounds on the physiology of fish will be reviewed.

iii) Other Pollutants

The concentrations and distribution of other relevant effluent pollutants such as nutrients, heavy metals and organic compounds causing organoleptic problems in fish and water will be evaluated. The possible influence of effluent pollutants on eutrophication of Lake Athabasca will be addressed.

iv) Emissions to the Atmosphere

The main emphasis will be on the emissions of chlorine compounds. Special consideration will be paid to the ultimate deposition of these compounds in the aquatic environment.

C. Summary of Major Conclusions and Recommendations

Conclusions will be drawn on the impact of the effluent discharge and air emissions of the proposed mill on water and air quality. River and lake ecology, water utilization, fisheries and the possible impact on the aquatic food chain, with special consideration of the toxicological effects, will be covered. Additional environmental control measures will be assessed to minimize the effects of chlorinated organic compounds and phosphorous on the river water quality and ecology. An evaluation of acceptable emission levels to the Athabasca River Basin will be given.

An oral Progress Report will be prepared and presented to ARC at a project review meeting in Helsinki (see Figure 1). At this time an Interim Report consisting of hard copies of the presentation material which summarizes the findings and conclusions will be prepared.

At the conclusion of this project two reports will be prepared. One of these will be technical and directed to the scientific community. The second report will be a condensed version of the Technical Report for release to the public.

APPENDIX II
LIST OF ABBREVIATIONS

LIST OF ABBREVIATIONS

Adt/d	air dried tonne of pulp per day
AEC	Alberta Energy Co.
ALPAC	Alberta-Pacific Pulp Mill Project
ANC	Alberta Newsprint Co.
AOX	adsorbable organic halids (refers to total organic chlorine compounds determined by SCAN W:9 method)
BCF	bioconcentration factor
BKME	bleached kraft mill effluent
BOD5	biological oxygen demand (in 5 days' incubation time)
C	chlorine stage in pulp bleaching
CD	chlorine stage in pulp bleaching (ClO2 less than 50 %)
CEPA	Canadian Environmental Protection Act
COD	chemical oxygen demand (dichromat method)
CPPA	Canadian Pulp and Paper Association
CTMP	chemithermomechanical pulp
D	chlorine dioxide stage in pulp bleaching (100 % technical ClO2)
DC	chlorine dioxide stage in pulp bleaching (Cl2 less than 50 %)
DBD	dibenzo-p-dioxin
DBF	dibenzofuran
DFO	Department of Fisheries and Oceans (in Canada)

DO	dissolved oxygen in river water
E	alkaline stage in pulp bleaching
EO	alkaline stage in pulp bleaching with oxygen reinforcement
EOP	alkaline stage in pulp bleaching with O2 and H2O2 reinforcement
EIA	environmental impact assessment
EOCl	extractable organic chloride (according to a Swedish standard)
EOX	extractable organic halides
FCC	Fletcher Challenge mill
FPPRI	Finnish Pulp and Paper Research Institute
GC/MS	gas chromatography/mass spectrometry
H	hypochlorite stage in pulp bleaching
HW	hardwood
MW	Millar Western Co.
N	nitrogen
NA	not applicable
NE	not established
O	oxygen delignification stage in pulping
P	phosphorus
PCDD	polychlorinated dibenzo-di-oxides
PCDF	polychlorinated dibenzofuran
P&G	Procter & Gamble mill

ppb	parts per billion
ppq	parts per quadrillion
ppt	parts per trillion
QA/QC	Quality Assurance/Quality Control
SFS	Finnish standard
SOD	sediment oxygen demand in the river
SW	softwood
TCDD	tetrachlorodibenzodioxin
TCDD–equivalent	concept based on the toxicity equivalence factors determined for most toxic congeners, in this report Nordic Proposal (Ahlberg 1989) is used unless otherwise defined
TCDF	tetrachlorodibenzofuran
TCG	tetrachlorguaiacol
TCU	true color units
TEQ	Toxicity Equivalency Factor
TMP	thermomechanical pulp
TOCl	total organic chlorine (according to a Swedish analytical method)
TOT P	total phosphorus
TRS	total reduced sulphur
TSS	total suspended solid
WW	Weldwood mill
7Q2	average 2 days' flow occurring once in 2 years
7Q10	average 7 days' flow occurring once in 10 years

APPENDIX III
PROPOSED PULP & PAPER EFFLUENT REGULATIONS

KG/TONNE

		ANNUAL AVERAGE	MAXIMUM MONTHLY	MAXIMUM DAILY
ALL MILLS except DISS. SULPHITE	BOD	5 - 10*	7.5 - 15*	12.5 - 25*
ALL MILLS except DISS. SULPHITE	TSS	7.5	11.25	18.75
DISSOLVING SULPHITE	BOD		>85%RED	>85%RED
DISSOLVING SULPHITE	TSS		38	70

* ALLOWED LIMIT MAY ONLY EXCEED MIN.VALUE IF REDUCTION ACROSS TREATMENT PLANT EXCEEDS 85% AND ALL REASONABLE ACTIONS TO REDUCE RAW WASTE LOAD WITHIN THE PLANT HAVE BEEN TAKEN

ACUTE TOXICITY

FINAL EFFLUENT AT 100% CONCENTRATION MUST NOT KILL MORE THAN 50% OF RAINBOW TROUT IN A 96HR. PERIOD.

COOLING WATER MAY NOT BE USED TO DILUTE FINAL EFFLUENT BEFORE DISCHARGE.

PROPOSED PULP & PAPER REGULATIONS CANADIAN ENVIRONMENTAL PROTECTION ACT

PROHIBITION

NO PERSON SHALL USE IN THE MANUFACTURE OF PULP

A. DEFOAMER CONTAINING MORE THAN 1). 40ppb DBF
OR 2). 20ppb DBD
B. WOOD OR WOOD CHIPS CONTAMINATED WITH PCP.

SUPPLIERS OF DEFOAMERS AND OF WOOD CHIPS SHALL CERTIFY THAT THEIR PRODUCTS MEET THESE REQUIREMENTS.

DIOXINS AND FURANS

PULP MILL EFFLUENTS SHALL CONTAIN NO MEASUREABLE CONCENTRATIONS OF 2378-TCCD[1] OR OF 2378-TCDF[2]

[1] LESS THAN QUANTITATION LIMIT OF HRGC/HRMS/DS
[2] LESS THAN 50ppq.

APPENDIX IV
SUMMARY OF MAJOR FISH SPECIES OF THE ATHABASCA RIVER

Species	Migrations	Spawning	Overwintering	Principal Foods	Predators	Competitors	Sensitive Locations and Times	Use by Man Within AOSERP Area
Lake Whitefish	Spawning migration Sep. to Oct. Post-spawning downstream movement begins immediately after spawning. Downstream fry migration probably April to June.	Mid-Oct. in Athabasca R. upstream of Fort McMurray (Cascade and Mountain Rapids).	Most likely in Lake Athabasca. Some overwintering suspected in Mildred Lake study area.	Benthic invertebrates.	Pike, Walleye, Burbot	Bottom feeders, White Suckers, Longnose Suckers.	Tributary mouths serve as resting areas during spawning migration. Egg incubation Nov. to March.	Domestic
Arctic Grayling	Migrate into tributary streams of Mildred Lake area in late April and early May. Seldom found in Athabasca R. during summer. Never taken in delta. Migrate out of tributaries just prior to freeze-up in October. Tributaries provide summer feeding for adults and nursery areas for fry.	Late April and early May. Muskeg R. and Steepbank R. are known spawning streams.	Young-of-year may overwinter in spawning streams. Age 1+ and older fish overwinter in Athabasca R. probably in upper Mildred area or above Fort McMurray.	Mature and immature stages of aquatic and terrestrial insects.	Walleye, Pike, but probably little predation while in tributaries.	Few, because of varied diet.	Spawning, feeding and nursery areas in tributaries. Over-wintering areas for young in tributaries. Susceptible to over-harvest by anglers.	Sport
Goldeye	Feeding migration into Athabasca R. occurs in early spring (April) under ice. All immature fish (ages 4 to 6). Leave feeding grounds in Sep. or Oct. for overwintering areas.	N/A As adults these fish will probably spawn in Peace-Athabasca Delta.	Suspected in Lake Athabasca or the Peace River.	Benthic and surface insects.	Pike, Walleye, Burbot	Few, because of varied diet.	Entire Athabasca R. up to (and probably) beyond) Fort McMurray serves as summer feeding area from April to October.	Commercial Domestic Sport

Species	Migrations	Spawning	Overwintering	Principal Foods	Predators	Competitors	Sensitive Locations and Times	Use by Man Within AOSERP Area
Northern Pike	Spawning movements in April and early May. Upstream migrations noted in some tributaries in May consist of ripe, spent and immature fish. Frequent lower reaches and mouth areas of tributaries during summer.	Probably late April and early May in marshy areas adjacent Athabasca R. and in some tributaries.	Probably Athabasca R. in Mildred Lake area. Those in delta may over-winter in Athabasca R. upstream of delta or in Lake Athabasca.	Mainly fish of several species Some immature insects.	Pike, Burbot, Walleye	Walleye, Burbot	Marshy areas in late April and early May. Lower reaches of tributaries important feeding areas in summer.	Sport Domestic
Lake Chub	Seldom found in delta but common in Mildred Lake study area and in tributaries. Fry appear in Athabasca R. in July. Few matures captured.	Locations unknown, Probably spawn in lower reaches of tributaries or along edges of Athabasca R. in Mildred Lake area during May or June.	Athabasca R. or tributaries in Mildred Lake study area.	Benthic invertebrates, (Mostly insects).	Walleye, Pike, Goldeye, Burbot.		Probably spawn in May or June.	None
Emerald Shiner	Spawning migration into Mildred study area assumed in May and June. Seldom enter tributaries. Most spawners age 2. Large post-spawning mortality suspected. Fry migrate down-stream during summer and remain in delta and/or Lake Athabasca until age 2.	Areas unknown but assumed in Athabasca R. within or upstream of Mildred Lake area. Probably spawn in June and July.	Suspected in delta and/or Lake Athabasca.	Benthic invertebrates (Mostly insects).	Walleye, Pike, Goldeye, Burbot		Spawning and egg incubation in Athabasca R. during June and July.	None

Species	Migrations	Spawning	Overwintering	Principal Foods	Predators	Competitors	Sensitive Locations and Times	Use by Man Within AOSERP Area
Spottail Shiner	Occur throughout study area but more common in delta study area. Fry appear mid-July but not abundant until mid-August. Seldom enter tributaries.	Unknown but probably Athabasca R. or lower reaches of some tributaries in late June or early July.	Probably Athabasca R. and Lake Athabasca.	Benthic invertebrates (Mostly insects).	Walleye, Pike, Goldeye, Burbot.		Spawning and egg incubation in late June or early July.	None
Flathead Chub	May be resident in Athabasca R. Mature fish more common in Mildred than in delta study area. Decrease in abundance after June suggests movement but extent unknown. Seldom enter tributaries. Young-of-year appear in July. Nursery areas suspected in delta or Lake Athabasca.	Areas unknown but assumed in Athabasca R. within or upstream of Mildred Lake area during June and July.	Unknown. Suspected within Athabasca R. and Lake Athabasca.	Varied. Mainly mature and immature insects, both aquatic and terrestrial.	Pike, Walleye Goldeye, Burbot	Few, because of varied diet.	Spawning and egg incubation probably in Athabasca R. from mid-June to mid-August.	None but sometimes taken by anglers.
Longnose Sucker	Spawning migration begins under ice in late April to early May. Post-spawning, downstream movement begins in mid-May. Fry emerge late May to early June. Fry migration June to August. Some non-spawners remain in tributaries until freeze-up.	Over gravel in tributaries during first half of May. Muskeg R., Steepbank R., MacKay R. are known spawning streams. Also spawn in Athabasca R. upstream of Fort McMurray.	Probably Lake Athabasca. Some young-of-year overwinter in spawning streams.	Benthic invertebrates but feed little during spawning migration.	Pike, Walleye, Burbot, Grayling, Flathead Chub	Bottom feeders, Lake Whitefish, White Suckers	Athabasca R. during migration of adults and dry (April to August). Spawning and nursery areas in tributaries (May to July). Mouth areas of tributaries are important nursery areas.	Domestic (Dog Food)

Species	Migrations	Spawning	Overwintering	Principal Foods	Predators	Competitors	Sensitive Locations and Times	Use by Man Within AOSERP Area
White Sucker	Spawning migration begins under ice in late April to early May. Downstream movement of spawners begins in mid-May. Fry emerge late May and early June. Fry migration June to August. Some non-spawners remain in tributaries until freeze-up.	Over gravel in tributaries during first half of May. Muskeg R., Steepbank R., MacKay R. are known spawning streams.	Probably Lake Athabasca. Some young-of-year overwinter in spawning streams.	Benthic invertebrates but feed little during spawning period.	Pike, Burbot, Grayling, Flathead Chub	Bottom feeders, Lake Whitefish, Longnose Suckers	Athabasca R. during migration of adults and fry. Spawning and nursery areas in tributaries (May to July). Mouth areas of tributaries are important nursery areas.	Domestic (Dog Food)
Burbot	A spawning migration into Mildred Lake area is suspected during the winter. Burbot leave Mildred area by mid-June. Young-of-year appear early June.	Spawning for this species usually occurs from Jan. to March under ice.	Probably Lake Athabasca.	Fish of many species.	Walleye, Pike	Walleye, Pike, Goldeye	Spawning and egg incubation in or upstream of Mildred Lake area Jan. to June.	Domestic Sport
Trout-perch	Probably resident in Athabasca R. Enter tributaries in May to spawn during late May or early June. Severe post-spawning mortality suspected. Fry emerge in early June and migrate out of tributaries to Athabasca R. during June and July.	Tributaries in late May and early June. Possibly Athabasca R. also.	Probably Athabasca R.	Benthic invertebrates (Mostly insects).	Walleye, Pike, Goldeye, Burbot		Spawning and egg incubation in tributaries from May to July.	None
Walleye	Spawning migration begins under ice in late April. Post-spawning downstream movement in May and June. Fry hatch in May to June and migrate downstream during June and July.	Sites unknown but probably in Athabasca R. upstream of Fort McMurray in late April and early May.	Suspected in Lake Athabasca.	Mainly fish of several species. Some aquatic insects.	Pike, Burbot, Walleye	Pike, Burbot	Athabasca R. during migration of adults and fry. Tributary mouths serve as resting areas for adults and as nursery areas.	Commercial Domestic Sport

APPENDIX V
DAILY FREQUENCY AND WEIGHT OF CONSUMPTION OF FOOD GROUPS

Table numbers are referring to the actual table numbers in the original document (Wein 1989).

TABLE 5.13
Mean Daily Frequency and Wight of Consumption of Food Groups, Part 1

Age and Sex Group	Milk and milk prod.		Meat, fish, poultry		Eggs and legumes		Vegetables		Fruits	
	Freq[2]	Wt[3]	Freq	Wt	Freq	Wt	Freq	Wt	Freq	Wt
Entire sample	2.0	172	2.0	204	0.5	44	0.5	258	1.5	258
Adolescents and Young Adults										
M	1.8	215	2.0	263	0.5	48	0.8	324	1.2	349
F	1.8	234	1.8	169	0.5	33	0.5	260	2.0	407
Middle Adults										
M	2.2	141	2.0	280	0.8	86	0.5	318	1.0	186
F	2.2	126	1.8	164	0.5	36	0.2	198	1.2	194
Older Adults										
M	2.0	115	2.2	257	0.5	46	0.5	262	1.0	131
F	2.5	163	1.8	144	0.2	23	0.2	215	1.5	182

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[1] Food groups shown here include both store-bought and country foods
[2] Number of times per day
[3] Grams per day

TABLE 5.14

Mean Daily Frequency and Weight of Consumption of Food Groups, Part 2

Age and Sex Group	Grains		Fats		Sweets		Miscellaneous	
	Freq[2]	Wt[3]	Freq	Wt	Freq	Wt	Freq	Wt
Entire sample	3.8	278	3.0	33	3.5	262	3.2	549
Adolescents and Young Adults								
M	4.0	350	3.0	45	3.8	495	2.0	304
F	3.8	280	2.0	25	3.0	268	1.2	200
Middle Adults								
M	3.8	355	3.8	49	4.8	336	5.0	916
F	3.2	216	3.2	29	3.2	112	4.2	379
Older Adults								
M	4.2	268	4.2	39	4.2	165	4.8	879
F	4.0	223	3.0	20	2.5	72	4.0	1006

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[1] Food groups shown here include both store-bought and country foods

[2] Number of times per day

[3] Grams per day

TABLE 5.15

Mean Daily Frequency and Weight of Consumption of Country Foods

Country Food Group

Age and Sex Group	All Country Foods		Meat and Birds		Berries		Fish	
	Freq[1]	Wt[2]	Freq	Wt	Freq	Wt	Freq	Wt
Entire sample	0.60	74	0.40	55	0.10	5	0.10	14
Adolescents and Young Adults								
M	0.55	78	0.45	67	0.05	4	0.05	7
F	0.32	38	0.25	29	0.05	2	0.05	7
Middle Adults								
M	0.72	114	0.52	89	0.15	15	0.05	10
F	0.60	57	0.42	46	0.1	3	0.08	8
Older Adults								
M	0.97	127	0.52	82	0.22	9	0.2	36
F	0.7	77	0.42	45	0.08	3	0.20	28

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[1] Number of times per day

[2] Grams per day